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APERTURE RADAR (SAR) IMAGERY CHARACTERISTICS
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STUDY OF SYNTHETIC APERTURE RADAR (SAR) IMAGERY CHARACTERISTICS

CONTRACT NO. NAS 6-2571

SUBMITTED TO
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WALLOPS STATION
WALLOPS ISLAND, VIRGINIA

GERA-2089

30 MAY 1975



GOODYEAR AEROSPACE CORPORATION
ARIZONA DIVISION • • • LITCHFIELD PARK, ARIZONA

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ABSTRACT

This is the final report to NASA Contract NAS 6-2571. Sources of geometric and radiometric fidelity errors in AN/APQ-102A radar imagery are discussed, along with a digital computer program to correct the distortions. The major effort, a computer program which will process digitalized recorded AN/APQ-102A phase histories into imagery, is described. All computer programs are listed.

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SECTION I - INTRODUCTION AND SUMMARY

This report describes the work accomplished on a study program entitled, "Study of Synthetic Aperture Radar Imagery Characteristics," funded under NASA Contract NAS 6-2571. The objective of the program was to analyze the characteristics of synthetic aperture radar (SAR) imagery and develop digital processing techniques to utilize this type of data in conjunction with other sensor data on the NASA earth resources program. Specifically, the major effort was directed toward producing the digital computer programs for the processing of data obtained from the AN/APQ-102A radar system.

The study program consisted of two major tasks: (1) the definition of SAR image characteristics, and (2) the development of digital computer programs to accept phase history data and generate a radar image normalized relative to both intensity and geometry.

Section II discusses the sources and magnitude of errors in the AN/APQ-102A imagery. The theoretical analysis consists of enumerating the known sources contributing to geometric distortion, determining the effect of each source, and combining to yield an overall estimate of the geometric fidelity of the imagery. Sources for geometric distortion fall into three categories: (1) sensing geometry, (2) radar equipment errors, and (3) errors in the aircraft inertial navigation system (INS) and altimeter. In addition to the theoretical analysis, the distortions in an AN/APQ-102A image of Wallops Island flown on 30 August 1973 were measured.

Section III describes the computer programs and procedures developed to process AN/APQ-102A phase history data. These programs and procedures were validated by actually processing imagery at the Wallops Station facility utilizing the Optronics Microdensitometer and the Honeywell 625 computer. This validation effort included the training of Wallops Station personnel, thus giving NASA the capability to process subsequent radar data without contractor support.

Conclusions are given in Section IV, and the appendixes contain program listings of all computer programs generated or used.

SECTION II - DEFINITION OF IMAGERY CHARACTERISTICS

1. GENERAL

The AN/APQ-102A has been quite successful in mapping for tactical purposes; however, its imagery has small geometric and radiometric fidelity errors which it would be desirable to remove when it is being used for cataloging earth resources. Some of the geometric errors are internally generated within the radar; however, these errors are generally small. The major sources of geometric errors are inertial system errors. Since these errors are not known for any particular flight, their effect (geometric distortion) must be measured by comparison with a map or other well-controlled data. This section discusses the error sources, their effect on geometric fidelity, and a method of measuring geometric distortions through the use of terrain features recognizable both in the radar image and on a map.

The basic design of the AN/APQ-102A includes features that minimize radiometric distortions that would be caused by sensing geometry (e.g., $\csc^2 \cos^{1/2}$ vertical antenna pattern). Radiometric distortions can be determined by measuring the deviation of the radar transfer function from the ideal or by imaging a calibrated radiometric range. Only the first of these methods is discussed.

2. GEOMETRIC FIDELITY ANALYSIS

The velocity and flight characteristics of the RF-4 aircraft and its avionics are used in the numerical calculation of the magnitude of the error components. The calculation is typical of the parameters of the flight of 30 August 1973. This analysis includes only fixed target imagery and only the modes listed in Table I.

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TABLE I - AN/APQ-102A HIGH-RESOLUTION OPERATING MODES

Mode	Altitude (ft)	Type of coverage	Range coverage (NMI)	Velocity (ft/s)
1	500 to 5,000	HR	0 to 10 both sides	700 to 1250
5	30,000 to 50,000	HR	5 to 15 both sides	700 to 2000
6	30,000 to 50,000	HR	10 to 30 left	700 to 2000
7	30,000 to 50,000	HR	10 to 30 right	700 to 2000

3. ACROSS-TRACK ERRORS

a. Ground Range Sweeps

The CRT recorder in the AN/APQ-102A employs ground range sweeps. Two characteristics of the sweep are normally considered relative to geometric fidelity, i.e., linearity and stability. Sweep linearity is expressed in terms of percent error in the distance between two points in the sweep interval. The linearity of the sweep of the AN/APQ-102A is ± 0.5 percent. The error in position of a target at one edge of the swath with respect to the other for a 10-NMI swath is

$$\pm(0.005) \times (5) (6080) = \pm 152 \text{ ft} \quad (1)$$

The long-term stability of this error should be good, and the error should be highly correlated between data films using the same recorder on successive missions. The expected dominant spatial frequency of this range scale factor error is one-half cycle per sweep length, with the error near the center of the sweep trace being very small.

b. Film Thickness Variations

Linear film thickness variations can cause errors on the order of four feet in the range direction. The spatial frequencies of these errors have not been determined.

c. Range Displacement Error from Target Altitude

Conversion from slant range measurement to ground range measurement depends on the relative altitude between the radar flightpath and a given target and thus is affected by terrain roughness, earth curvature, etc. No error is attributed to the radar for this operation.

4. ALONG-TRACK ERRORS

a. Recorder Film Drive Error

The major error in film drive is caused by the error in the measurement of ground-speed. The accuracy of the velocity measuring equipment is about nine feet per second. Thus, the linear error in target location resulting from errors in velocity is

$$E_V = \frac{V_E}{V_Y} \times D \quad , \quad (2)$$

where

V_E = error in velocity

V_Y = aircraft velocity

D = the along-track distance over which error is to be considered.

In a high-speed mode over a five-mile distance, the linear error is

$$\frac{9}{1500} \times 5 \times 6080 = 180 \text{ ft} \quad . \quad (3)$$

It can be further assumed that a three-mil peak sinusoidal error is present because of eccentricity of the film metering drum. This would be equivalent to a three-foot error.

b. Film Thickness Variations

The errors from film thickness variations are estimated to be small (about four feet).

c. Clutterlock Stability

The stability of the clutterlock motion compensation loop is about five Hertz and would produce an error in the longitudinal (y) direction according to the following relationship:

$$dy_n = R_n \left[\frac{df_d \lambda}{2V_y} \right] \quad (4)$$

where

$$\text{frequency error} = df_d = 5 \text{ Hz}$$

$$\text{wavelength} = \lambda = 0.1 \text{ ft}$$

$$\text{groundspeed} = V_y = 1500 \text{ ft/s}$$

$$\epsilon = \text{relative error}$$

$$\epsilon = dy_1 - dy_2$$

$$\epsilon = (R_{\min} - R_{\max}) \frac{df_d \lambda}{2V_y}$$

$$\epsilon = \frac{30,400 \times 5 \times 0.1}{2 \times 1500} = 5 \text{ ft}$$

This is a skew-type error, and its frequency is estimated to be very low.

d. Correlator Film Drive Error for Optically Processed Imagery

Aspect ratio error contributes a small, steady-state error in the image azimuth scale factor. This error is held to less than a resolvable element and is estimated

to be 15 feet. Data film drive error resulting from metering drum eccentricity is the same as that of the recorder and is three feet. The image film metering drum eccentricity permits a maximum sinusoidal error of 23 feet peak at a period of 3.9 NMI.

e. Residual Error from Motion Compensation Instrumentation

Compensation for sideways motion in the AN/APQ-102A radar is achieved in the following manner. An antenna-mounted accelerometer system measures the sideways accelerations which are integrated and combined with the clutterlock-measured velocities. The clutterlock takes an average of range samples at intervals along the entire 10-mile swath. The motion compensation signal thus derived is applied at midrange. Thus, no along-track error exists at this point; however, an error does exist on each side of the midpoint, with maximum error at maximum and minimum ranges.

To obtain an expression for this error, consider a velocity in the X direction, V_X . A correction is made so that no error exists at Y_0 . However, there is a difference between the hyperbola on which mapping is occurring and the straightline correction that is applied. From Figure 1, the following expressions may be written:

$$Y_\psi = (R^2 + h^2)^{1/2} \cos \psi \quad (5)$$

$$Y_0 = \frac{V_X}{V_Y} R_0 \quad (6)$$

$$Y = \frac{V_X}{V_Y} R \quad (7)$$

$$\frac{V_X}{V_Y} R_0 = (R_0^2 + h^2)^{1/2} \cos \psi \quad (8)$$

$$\cos \psi = \frac{Y}{(R_o^2 + h^2)^{1/2}} \quad (9)$$

$$Y_\psi = (R^2 + h^2)^{1/2} \frac{\frac{V_X}{V_Y} R_o}{(R_o^2 + h^2)^{1/2}} = \frac{(R^2 + h^2)^{1/2}}{(R_o^2 + h^2)^{1/2}} R_o \frac{V_X}{V_Y} \quad (10)$$

The along-track error is

$$\begin{aligned} Y - Y_\psi &= \frac{V_X}{V_Y} R - \frac{V_X}{V_Y} R_o \frac{(R^2 + h^2)^{1/2}}{(R_o^2 + h^2)^{1/2}} \\ &= \left[R - R_o \frac{(R^2 + h^2)^{1/2}}{(R_o^2 + h^2)^{1/2}} \right] \frac{V_X}{V_Y} \quad (11) \end{aligned}$$

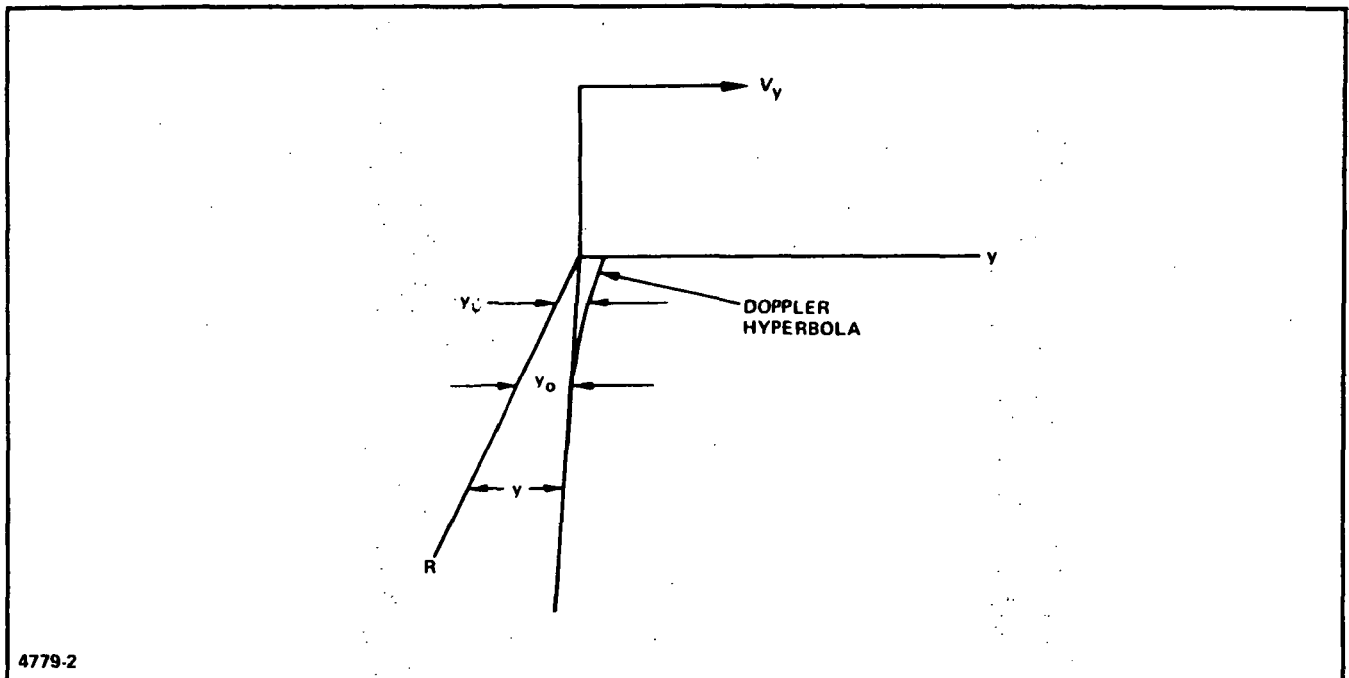


Figure 1 - Geometry and Motion Compensation Error

If the velocity, V_X , is 10 ft/s, V_Y is 1500 ft/s, R is 20 miles, R_o is 15 miles, and h is 40,000 ft, the error is

$$Y - Y_\psi = 26.7 \text{ ft} \quad . \quad (12)$$

f. Effect of Clutterlock and Across-Track Velocity Measurement Error

An across-track velocity measurement error introduces a squint or skew into the final image. An across-track velocity measurement error of 6 ft/s at 1500 ft/s produces a pointing error of

$$\text{ANGULAR } \epsilon_{\text{CTV}} = \frac{6}{1500} = 4 \times 10^{-3} \text{ radian} \quad . \quad (13)$$

The linear error along track of a target on one edge of the swath with respect to the other is

$$\begin{aligned} \epsilon_{\text{CTV}} &= \frac{\Delta V_X}{V_Y} (R_{\text{MAX}} - R_{\text{MIN}}) \\ &= \frac{6}{1500} (10) (6080) \\ &= 243 \text{ ft} \quad . \end{aligned} \quad (14)$$

g. Effect of Vertical Velocity Measurement Error

An expression relating vertical velocity to along-track error can be developed similar to that for across-track velocity:

$$\epsilon_{\text{VV}} = h \left[\frac{(R^2 + h^2)^{1/2}}{(R_o^2 + h^2)^{1/2}} - 1 \right] \frac{V_Z}{V_Y} \quad . \quad (15)$$

For the conditions

$$V_Z = 3.5 \text{ ft/s}$$

$$V_Y = 1500 \text{ ft/s}$$

$$h = 40,000 \text{ ft}$$

$$R = 20 \text{ NMI}$$

$$R_o = 15 \text{ NMI} ;$$

therefore,

$$\epsilon_{VV} = 26.9 \text{ ft}$$

h. Effect of Vertical Velocity Measurement Error

The along-track effect of vertical velocity measurement error may be determined from the expression

$$\epsilon \Delta V_Z = \frac{h}{V_Y} \times \Delta V_Z \quad (16)$$

For the parameters

$$\Delta V_Z = 2 \text{ ft/s}$$

$$V_Y = 1500 \text{ ft/s}$$

$$h = 40,000 \text{ ft}$$

the along-track error resulting from vertical velocity measurement error is

$$\epsilon \Delta V_Z = \frac{40,000}{1500} \times 2 = 53.3 \text{ ft} \quad (17)$$

i. Antenna Pitch and Yaw Errors

Errors in antenna pitch and yaw will affect along-track geometric fidelity. The result is that the clutterlock attempts to correct for the error, causing a skew in the imagery. Consider the geometry of Figure 2. The aircraft is flying at velocity with an antenna pitch of θ_p and yaw of θ_a . The error in the along-track direction is the mismatch between the best-fit doppler line and the antenna pattern intersecting the ground. This error is $Y - Y_\psi$.

From Figure 2, the following expressions may be written:

$$Y_\psi = (R^2 + h^2)^{1/2} \cos \psi \quad (18)$$

$$Y = R\theta_a + h\theta_p \quad (19)$$

$$Y_o = R_o\theta_a + h\theta_p \quad (20)$$

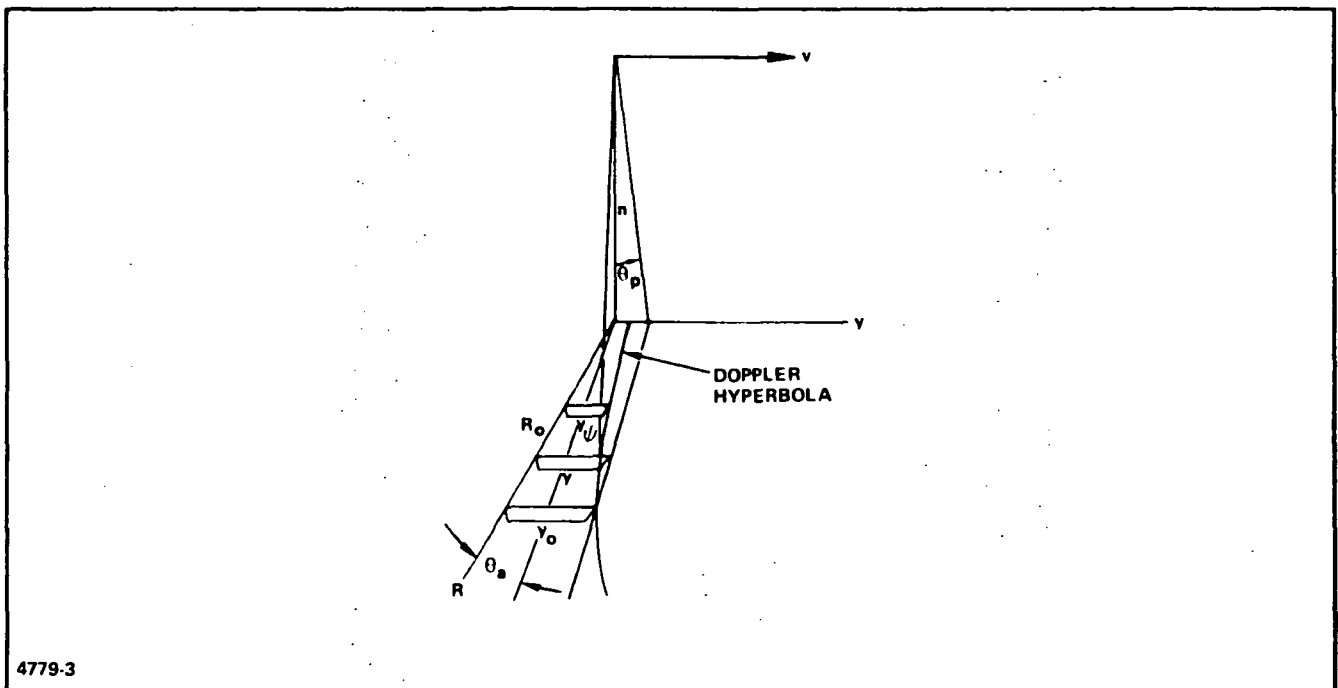


Figure 2 - Geometry of Antenna Pitch and Yaw Error

$$R_o \theta_a + h \theta_p = (R_o^2 + h^2)^{1/2} \cos \psi \quad (21)$$

$$\cos \psi = \frac{R_o \theta_a + h \theta_p}{(R_o^2 + h^2)^{1/2}} \quad (22)$$

The error in along-track position is

$$Y - Y_\psi = R \theta_a + h \theta_p - (R^2 + h^2)^{1/2} \cos \psi \quad ; \quad (23)$$

and, substituting for $\cos \psi$, the following is obtained:

$$Y - Y_\psi = R \theta_a + h \theta_p - \left[\frac{R^2 + h^2}{R_o^2 + h^2} \right]^{1/2} (R_o \theta_a + h \theta_p) \quad (24)$$

The error at R_o , Y_o is zero but increases as R increases or decreases from R_o . Therefore, R_o is placed at the midswath position, and R may vary five NMI on either side.

For the following conditions,

$$R = 20 \text{ NMI}$$

$$R_o = 15 \text{ NMI}$$

$$h = 40,000 \text{ ft}$$

$$\theta_a = 0.25 \text{ deg}$$

$$\theta_p = 0.25 \text{ deg} \quad ,$$

an along-track error of 90 ft occurs.

j. Aircraft Turning Error

The inability of the aircraft to fly a perfectly straight path introduces errors in the along-track direction. When the aircraft goes into a slow turn within the time constants of the clutterlock, the clutterlock is able to keep the physical beam oriented on the zero doppler line. However, the radar thinks it is following a straight line flightpath and, as a result, the imagery is skewed. The geometry of this situation is depicted in Figure 3. Here, r is the uncompensated turning radius of the aircraft, R is the range of interest of the radar, s is the length of the ground track in rotating through the angle θ , and S is the distorted, recorded length of the flightpath. The error caused by the aircraft turn may be written as

$$\epsilon_T = \frac{S - s}{s} = \frac{(r + R)\theta - r\theta}{r\theta} = \frac{R}{r} \quad (25)$$

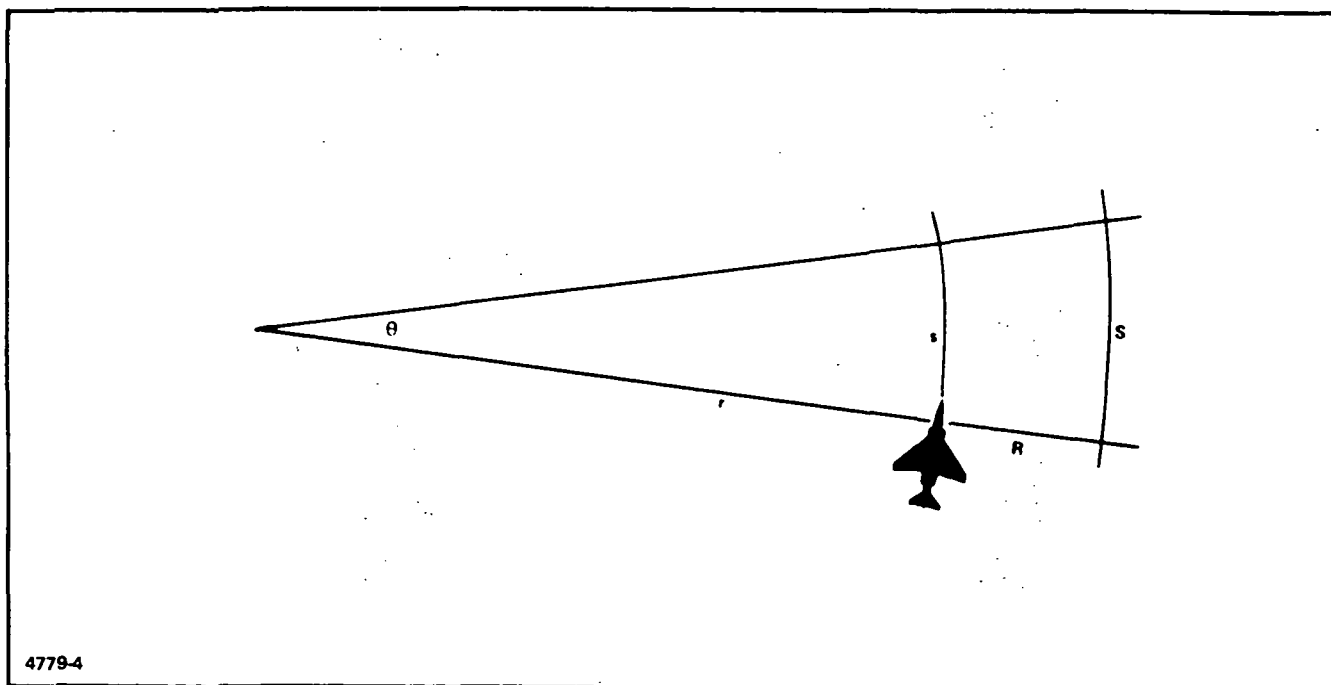


Figure 3 - Geometry of Errors Resulting from Uncompensated Turn

It is difficult to determine what the minimum uncompensated turning radius for the RF-4 or C-54 is, but the manufacturer of the RF-4 has indicated that it will fly straight with a minimum turn radius of 2650 NMI. Therefore, the error resulting from a turn expressed in percent is

$$\epsilon_T = \frac{R}{r} = \frac{10}{2650} = 0.00378 = 0.38 \text{ percent} \quad (26)$$

When one considers a strip five NMI long, the turning error is

$$\epsilon_T = (0.0038) \times 5 \times 6080 = 115 \text{ ft}$$

5. MEASUREMENT OF GEOMETRIC ERRORS

a. General

It can be seen from the foregoing that most of the fidelity errors are random and are irreducible prior to imaging, because they represent the utilization of onboard sensors and their attendant errors. Certain errors such as residual motion compensation error and the skew introduced by use of an offset frequency for demodulation could be removed after flight if the offset frequency and the three-axis translation of the aircraft were recorded during flight. These data, however, are not available in the AN/APQ-102A, and hence the aforementioned errors are not separable from the random errors.

As a postflight procedure, the processed radar image may be rectified by use of a computer program which does a least-square-error fit using precisely imaged points whose geographic coordinates are accurately known. Care must be taken that points utilized are coincident with the points whose coordinates are known.

b. Program Rationale

For the distribution correction program, the following radar image distortions were considered:

1. Scale (range versus track) - caused by the separate scaling mechanisms involved (in the radar) in the track and range directions
2. Skew - caused by either radar antenna or correlator slit misalignment (results in range and track nonorthogonality).
3. Residual distortion - that which remains after items 1. and 2. have been accounted for (caused by height differences between the radar ground plane and the elevation of objects in the ground area being imaged, nonlinearities in the recording CRT, measurement errors, etc.).

c. Program Steps

Since the program determines the distortion relative to (radar) range and track, a prerequisite for the analysis is that the radar image measurements (of identified ground control points) be performed with the X-axis of the measurement device aligned with the track direction of the radar. The steps taken by the program in analyzing distortion are summarized as follows:

1. The ground coordinates of the control points are preliminarily aligned with the image coordinate system. This is done by determining the relative orientation of two designated control points in both the image and ground frames and rotating the ground system to coincidence. For correctly signed printout of scale, skew, and distortion, it is desirable to choose the ground axes to lie within 45 degrees of the image coordinate

system (for an existing system, this is accomplished by controlling the sign and (X-Y) designation of the axes). The designation of alignment points (as a program parameter) prevents the use of points known to have a high probability of substantial relative distortion (e.g., points extremely close together). The selection of two widely spaced points will suffice for the initial alignment

2. A least-squares fit between image and ground range coordinates is performed. The range errors remaining after the fit are computed, and the linear correlation coefficient between range errors and track coordinates is determined (if a nonzero coefficient exists, it indicates a residual misalignment). The ground coordinates are then rotated to make the coefficient zero. This process prevents individual control point errors from introducing substantial alignment errors
3. A least-squares fit between the range image and ground coordinates is computed and residual errors determined (at ground scale)
4. Track image and ground coordinates are scaled via a least-squares fit and average error determined. Skew is then introduced into the image coordinate system via two equations:

$$Y' = Y \quad (27)$$

and

$$X'(I) = X(I) + A \cdot Y(I) \quad (28)$$

where

(X, Y) = original image coordinates

(X', Y') = skewed coordinates

A = tangent of skew angle.

The skew angle is varied (in sign and magnitude) until track errors are minimized (as measured by successive least-squares fits)

5. Several types of analyses are then performed by the program to demonstrate the relative contribution of various error sources. In each of them, the residual error variance and individual point errors (ground scale) are computed (and displayed for examination) after various types of image correction are introduced. The four types of correction are:
 - a. A magnification equal to the average (range and track) scaling difference between image and ground coordinates
 - b. Differential scale correction
 - c. Magnification plus skew correction
 - d. Differential scale and skew correction.

The image range scale, track scale, and skew are displayed. Plots are created (using CalComp software) which illustrate the ground position and residual error of the control points after the various types of correction.

d. Program Parameters

The program listing is given in Appendix A. The utilization of the results to restitute digitally processed imagery is discussed in Section III.

Program parameters are as follows:

ALPHA 1 - ALPHA 4	Analysis section headers
N	Number of control points
N1, N2	Number (corresponding to program order) of point pair to be used for initial alignment. N1 and N2 should be ordered so that N1 has a smaller track coordinate than N2 (however, $N1 < N2$ need not be true; <u>i.e.</u> , control points may be entered in any order)
SCPLT	Scale of plots (ground units/inch) which are created of control point positions
SCERR	Scale of error vectors
(P(I), Q(I))	Ground coordinates of control point
(X(I), Y(I))	Image coordinates of Ith control point
A(I)	Alphanumeric control point designator.

c. Results

A section of the AN/APQ-102 data film which was flown for NASA on the 30 August 1973 flight was optically correlated on a laboratory correlator, and the portion of the imagery around Wallops Island was analyzed. Sixteen points were used, of which coordinates for 6 were from triangulation and 10 from a map. After distortion correction, the mean error along track was zero with a standard deviation of 77.52 meters and mean across-track error of 7.2 meters, with a standard deviation of 87.7 meters.

6. RADIOMETRIC ERRORS

a. General

As mentioned previously, the transfer function of the AN/APQ-102A was designed to compensate for sensing geometry, ideally resulting in no radiometric distortion. To the extent that the radar transmitted power and the receiver gain remain constant (this can be accomplished by disabling the automatic gain control), the radar can be designed to compensate for changes in slant range and depression angle. These compensations are accomplished with sensitivity time control and a vertical antenna pattern designed for uniform illumination as a function of depression angle. Deviations (from the ideal) of these functions can cause radiometric errors.

b. Sensitivity Time Control (STC)

Reference 1^a contains instructions on how to adjust the STC to give the desired signal. This description includes wave shapes and is considered the best data available. The STC so adjusted requires no correction. The STC is turned off in modes used above 30,000-ft altitude and does not apply to the flight of 30 August 1973.

^a USAF T.O. 12P3-2APQ102-2-4. Radar Mapping Set, AN/APQ-102 and AN/APQ-102A (Frequency Converter-Transmitter CV 1678/APQ102), Chapter 11.

c. Antenna Illumination

It can be shown that if the vertical antenna pattern has a gain

$$G = K \csc^2 \theta \cos^{1/2} \theta \quad , \quad (29)$$

then the terrain would be uniformly illuminated as a function of depression angle θ .

Such a pattern can be synthesized over a limited angle. In the AN/APQ-102A, the pattern is normalized at 18 deg. Figure 4 shows the theoretical vertical antenna pattern of the AN/APQ-102A, together with the tolerances in gain. The standard deviation of the one-way gain from uniform illumination is less than 0.5 dB. The antenna pattern of the arrays to be used can be measured and the deviation between measured values and the ideal $\csc^2 \theta \cos^{1/2} \theta$ determined. It was anticipated that the measured antenna pattern could be used to make radiometric corrections to the imagery of Wallops Island made on 30 August 1973. However, it has been determined that USAF records do not make this possible. Therefore, no corrections for the antenna pattern were made. The image distortion program discussed in Section III has such provisions.

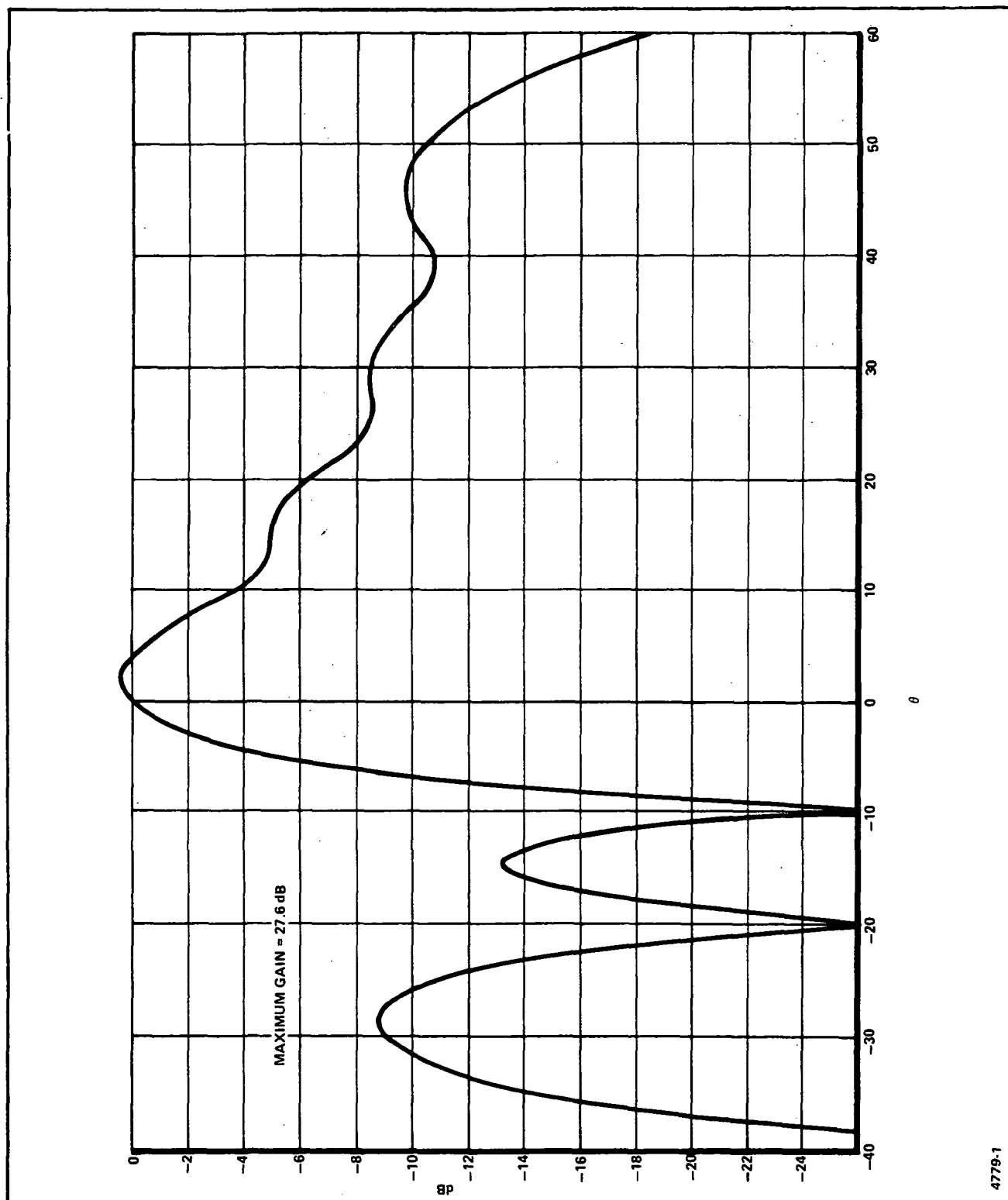


Figure 4 - Theoretical Vertical Antenna Pattern at Horizontal Boresite

SECTION III - DIGITAL PROCESSING OF IMAGERY

1. DIGITAL AZIMUTH PROCESSING

The processing described in this section will accommodate AN/APQ-102 radar data which has been range compressed, recorded optically, scanned, and digitized for processing. The azimuth compression will be performed by a high-speed digital computer. The data flow diagram is given in Figure 5. The processing will be performed to obtain 30-ft-resolution imagery with the option of either one or two azimuth looks. If more rapid processing of the data is desired, the azimuth resolution may be degraded.

The data will be processed for an azimuth offset that is nominally $PRF/4$. In actuality, the azimuth offset frequency is not exactly known, and the data processing must take this into account. To maintain low sidelobe levels, an oversampling factor of at least four will always be maintained. The sampling rate of the input data will not be reduced until azimuth compression is being performed.

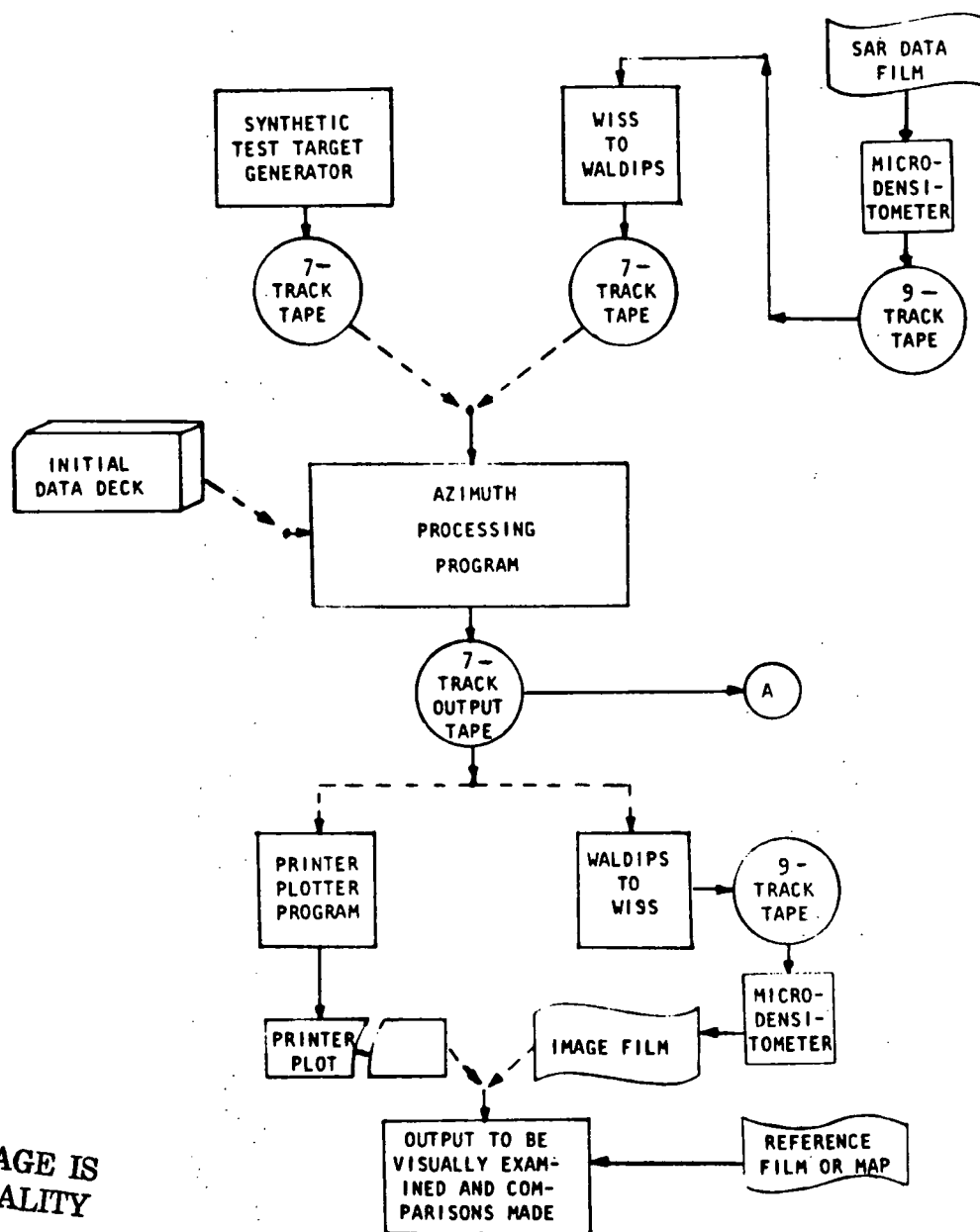
The implications of the foregoing may be better understood by examining the fundamental formulas for azimuth compression. The synthetic aperture length which must be flown to attain a desired 3-dB azimuth resolution, W_A , is

$$L_{SYN} = \frac{0.88\lambda R_s}{2W_A}, \quad (30)$$

where R_s is the slant range to the target measured on a line perpendicular to the flight-path, and λ is the wavelength of the transmitted signal.

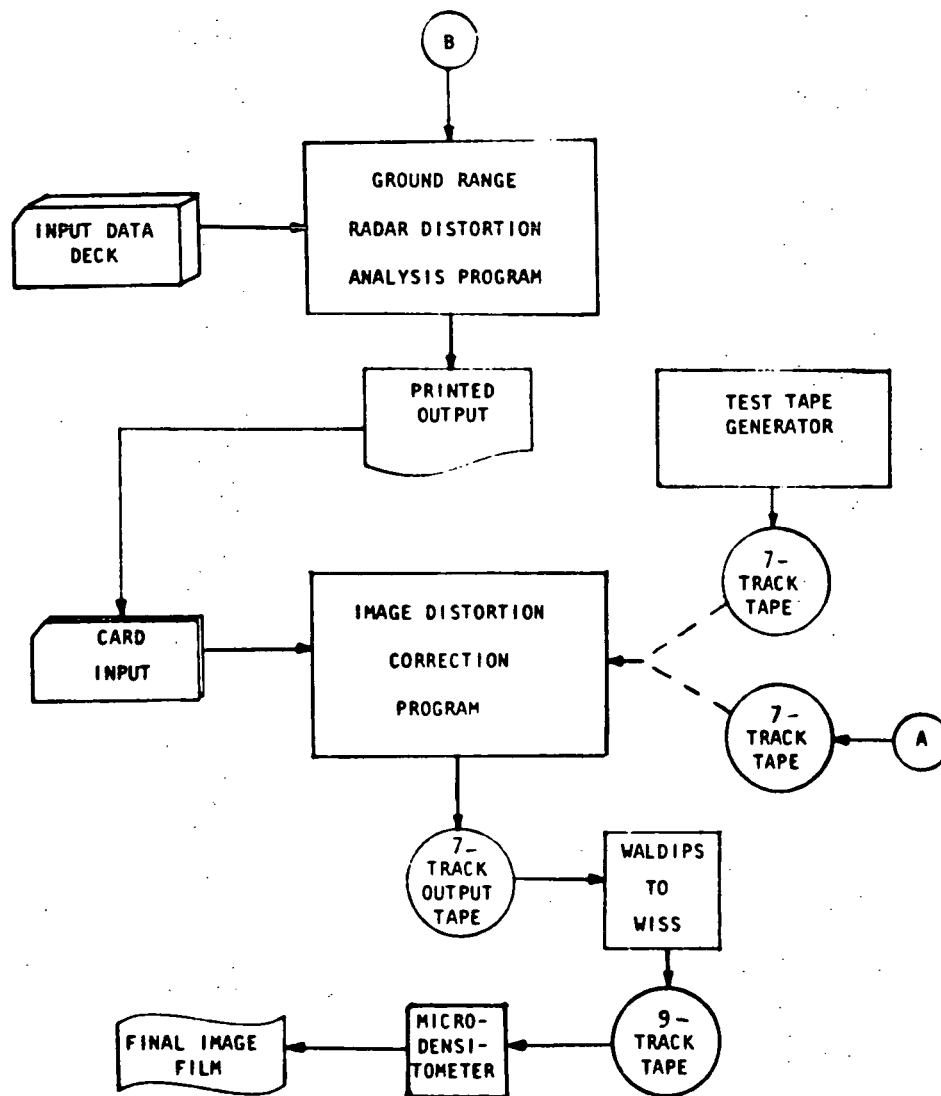
However, when the phase history of a point target which has been collected over the required L_{SYN} is compressed (i.e., processed in a matched filter), the resultant sidelobes of the $\sin(x)/x$ compressed waveform have a -13.6-dB peak and decay slowly.

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Figure 5 - Digital Processing of SAR Data-Flow Diagram (Sheet 1 of 2)



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Figure 5 - Digital Processing of SAR Data-Flow Diagram (Sheet 2 of 2)

These sidelobes present a problem in that the sidelobes of a large target may have larger amplitudes than the mainlobe of a target, and hence mask it. To prevent this from occurring, a weighting function is applied to the return phase history. Basically, the weighting function reduces the sidelobes by the application of a symmetrical taper across the azimuth phase history of a target. This symmetrical attenuation, however, causes a broadening of the mainlobe of the target when azimuth compression is performed. To maintain the desired resolution, yet achieve a low sidelobe level, excess azimuth bandwidth is required.

Typical of the weighting functions which may be applied are Taylor aperture functions. A Taylor aperture function which suppresses the peak sidelobe to -30 dB will broaden a point target's mainlobe by a factor of 1.42. When this weighting function is used,

$$L_{\text{SYN}} = \frac{1.25\lambda R}{2W_A} \quad (31)$$

Processing is being performed for a finer resolution than is specified, with the knowledge that the weighting function is being utilized and will broaden the mainlobe to that desired.

If the antenna's real azimuth beamwidth, β , (here considered to be 3-dB beamwidth) is capable of illuminating more azimuth extent than is required for a desired resolution, i.e., if

$$R_s \beta > L_{\text{SYN}} \quad (32)$$

then the excess illuminated area may be used to form more than one synthetic aperture. For the AN/APQ-102A system, the 2-way 3-dB beamwidth is approximately 1 degree, which would theoretically imply that 8 synthetic apertures for 30-foot resolution exist between the 3-dB points of the antenna beam:

$$\frac{R_s \beta}{L_{\text{SYN}}} = \frac{R_s (1 \text{ deg})}{57.3} \bigg/ \frac{K\lambda R_s}{2W_A} = 8.37 \quad (33)$$

However, because the limitations of the motion compensation INS, azimuth recorder bandwidth, etc., blurring of the image will possibly occur if more than two looks are combined. Thus, for this problem,

$$L_{\text{SYN}} = 2.083 \times 10^{-3} \times R_s \times \text{number of looks} \quad , \quad (34)$$

where L_{SYN} is the synthetic aperture length in feet, R is the slant range in feet, and the number of looks is either one or two.

The AN/APQ-102 radar has a PRF of $1.1 V$, where V is the aircraft velocity in feet per second. Therefore, a sample of the terrain is collected once per 0.9091 ft of aircraft travel. This sampling is greatly in excess of that necessary for 30-ft resolution, which is

$$\text{minimal sample spacing} = \frac{30}{2 \times 1.25 \times \text{number of looks}} \text{ ft} \quad . \quad (35)$$

(The factor of 1.25 in the denominator accounts for the excess bandwidth required to preserve resolution when using the weighting function.) It is necessary to have this high PRF to keep the spectrum which lies within the antenna's mainbeam unambiguous.

The unambiguous bandwidth of the sampled spectrum lies from zero frequency to $1/2$ PRF, or 0.55 cycle/ft. The clutterlock, however, keeps the antenna, and hence the doppler spectrum within its mainlobe, centered on zero doppler. Therefore, it is necessary to translate the return mainlobe spectrum up in frequency so that a frequency of -0.275 cycle/ft will lie at zero frequency, and a frequency of $+0.275$ cycle/ft will lie at 0.55 cycle/ft. This is accomplished by mixing the return with an azimuth offset frequency of $1/4$ PRF. The translated return spectrum is illustrated in Figure 5. Energy at frequencies above ± 0.275 cycle/ft will fold back into the spectrum of interest. However, as is illustrated by the dashed lines in Figure 6, this energy is heavily attenuated by the rolloff of the antenna's mainlobe. The peak sidelobes of the AN/APQ-102A 2-way antenna pattern are more than 26 dB down, and thus the energy in them will contribute little to the processing noise.

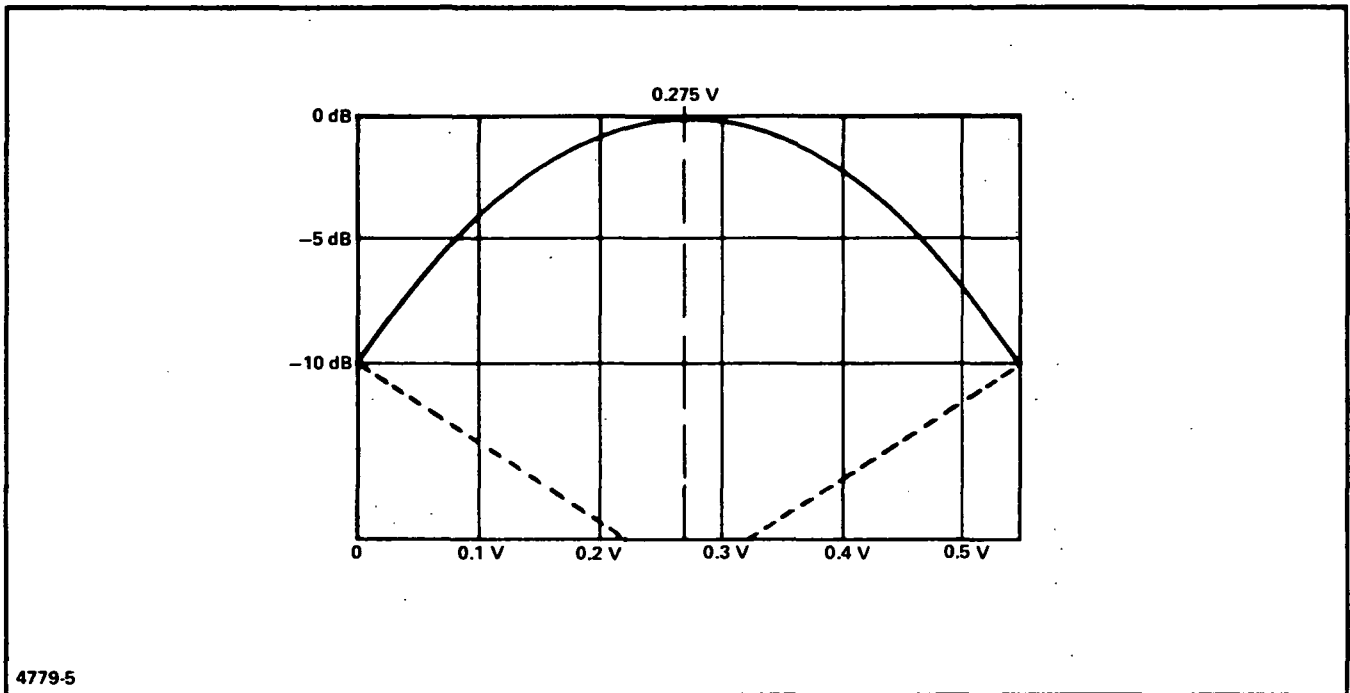


Figure 6 - Antenna Azimuth Frequency Response

The spatial bandwidth required to process 1 look for 30-ft, 3-dB resolution with 30-dB peak sidelobes is $(1.42)(0.88)/(30) = 0.04617$ cycle/ft. The factor of 1.42 is the excess bandwidth ratio required for the sidelobe control. Thus, the bandwidth of the spectrum which will enter the processor is in excess of that necessary to process one look by the ratio of $(0.55)/(0.04617) = 13.2$. As will be detailed later, the input bandwidth can be reduced by filtering to reduce the excess bandwidth and improve the signal-to-noise ratio. (Note that only $8.37/13.2$ of the unambiguously sampled data lies within the 3-dB antenna beamwidth, as was shown in Equation (33)).

The radar's azimuth bandwidth and sampling rates having been examined, the effects of scanning the optically recorded data and digitizing samples will be considered. For each range element, an azimuth sample has been taken and recorded on film for each 0.9091 ft of aircraft travel. When this data is scanned, however, a sample is taken from the film at the equivalent of once for each 0.826 ft of aircraft travel, which introduces

an effective increase in the azimuth sampling of a factor of 1.10. It must be understood that no increase in the information bandwidth has occurred, that having been restricted by the original PRF. However, there is a translation of all frequencies because of the resampling. All data must be treated as though the spatial bandwidth were $(0.55)(1.1) = 0.605$ cycle/ft, even though no information lies in the portion of the unambiguous spectrum resulting from the different input and output data rates.

The digitized data will be treated as if the original PRF produced a factor of $(13.2)(1.1) = 14.52$ in excess bandwidth over that required for a single azimuth look. Each azimuth look will thus occupy $(0.04167/0.605) \times 100 = 6.9$ percent of the unambiguous sampled bandwidth.

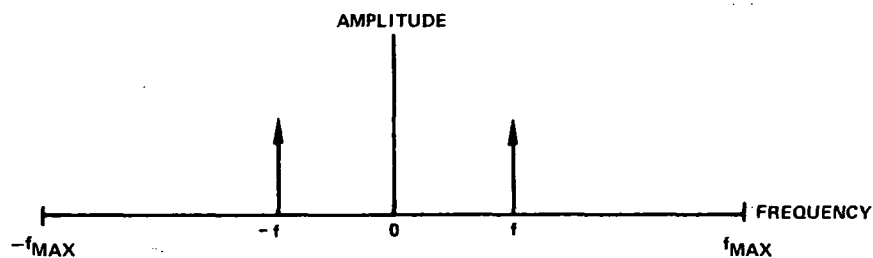
The first operation in the digital processing of the data is to bandpass only those frequencies necessary for azimuth compression, and thereby improve the signal-to-noise ratio by reducing the noise bandwidth. This is done in the azimuth prefilter, which has been designed (described below) to have a nominal center frequency of 0.4545 (i. e., $\text{PRF}/4/1.1$) of the sampled bandwidth and have 0.04167 and 0.08334 cycle/ft spatial bandwidths for the one- and two-look cases, respectively.

The two azimuth prefilter functions are "window function" designs.^a To produce a window function with a desired center frequency and bandwidth, the following procedure is employed (the steps are illustrated in Figure 7):

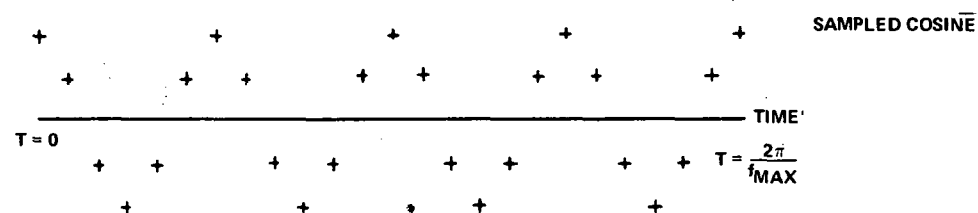
1. In the frequency domain, place an impulse at the desired fraction of the bandwidth for which the filter's center frequency is to lie, and at the corresponding negative frequency
2. Take the inverse discrete Fourier transform (IDFT) of this spectrum. The result will be a sampled cosine in the time domain having an integer number of cycles over the time extent of the IDFT output

^aGold, B. and Rader, C.M.: Digital Processing of Signals. McGraw-Hill, 1969, pp. 217-231.

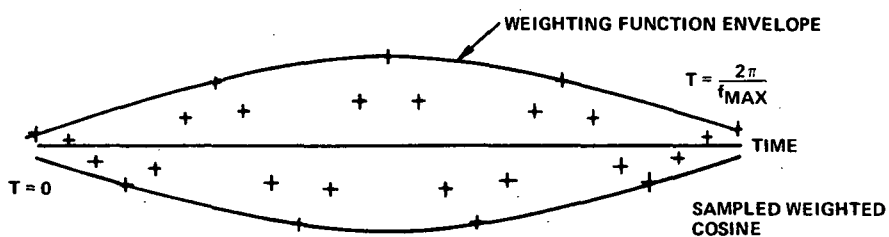
STEP 1



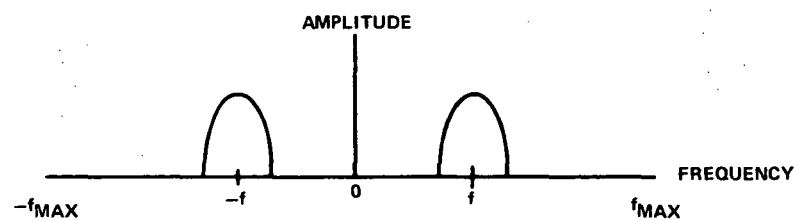
STEP 2



STEP 3



STEP 4



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Figure 7 - Window Filter Design

3. A weighting function, in this case, a 40-dB Taylor function, is point by point multiplied with the sampled cosine. This is the filter function
4. A discrete Fourier transform (DFT) is taken of the product. This shows the bandpass of the filter. Note that if no window function were applied, the step 4 output would have the shape of $\sin(x)/x$, which is the transform of a pulsed cosine.

The selection of the number of points in the window function design depends essentially upon three factors:

1. The accuracy to which the center frequency of the filter must be positioned
2. The bandwidth of the filter
3. The rolloff rate and minimum stop-band attenuation of the filter.

For the two azimuth prefilter functions, the desired center frequency of both is $0.4545 = 5/11$. Thus, as an impulse is needed at both positive and negative frequency, the length of the reference function should be a multiple of $2 \times 11 = 22$ points.

The bandwidths desired are 0.04167 and 0.08334 cycle/ft spatial bandwidths. As the 3-dB width of the $\sin(x)/x$ function mentioned in step 4 of the foregoing is $0.88 \times 2/N$ of the bandwidth, where N is the number of points in the sampled cosine, and as the 40-dB Taylor weighting broadens this by a factor of 1.42, then for the 0.04167 cycle/ft filter,

$$0.88 \times 2 \times 1.42 \div N = \frac{0.069}{1.1} \rightarrow N = 40 \quad , \quad (36)$$

and for the 0.08334 cycle/ft filter,

$$0.88 \times 2 \times 1.42 \div N = \frac{0.138}{1.1} \rightarrow N = 20 \quad . \quad (37)$$

Thus, for the filters, $N = 44$ and $N = 22$ provide excellent choices, with the impulses at (10, 34) for the first and at (5, 17) for the second. The taper over the amplitude of the filter's output spectrum will be used as part of the weighting to control the azimuth sidelobes (described in Equation (31)).

The two filters are readily translatable to different center frequencies simply by changing the position of the impulses in step 1. The narrow bandwidth filter can be stepped in increments of 0.04545 of the sampled bandwidth and the wider bandwidth filter in steps of 0.9091 of the sampled bandwidth. Finer steps can be obtained by increasing the number of points in the reference function and changing the window function accordingly.

The azimuth prefilter is a nonrecursive, convolution filter. In nonrecursive filters, the output is not fed back to the input. Although filters with feedback (i.e., recursive filters) have shorter reference functions than do nonrecursive filters, they suffer in that they allow a noise buildup because of signal quantization and do not offer the truly linear phase characteristic which nonrecursive filters provide. Hence, nonrecursive designs are considered superior for this application.

In the nonrecursive filter, N consecutive data points are multiplied by the N corresponding filter reference function points; the N products are summed, and the result is obtained. The oldest input data point is discarded, the remaining $N - 1$ data points are shifted one position, a new data point is entered, and the multiplication and summation process is repeated. Thus, for every data point entered, there is one data point output.

After azimuth prefiltering has been performed, the data will be compressed to its ultimate azimuth resolution. The length of the synthetic aperture required to compress an azimuth return was shown in Equation (34) to be equal to $2.083 \times 10^{-3} \times R_s \times \text{number of looks}$, where R_s is the slant range to the target in feet. A digitized data sample is taken from the data film once for every 0.826 ft of aircraft travel. The number of data points contained in the synthetic aperture length, N , is given by

$$N = 2.52 \times 10^{-3} \times R_s \times \text{number of looks} \quad , \quad (38)$$

where R_s is in feet.

The azimuth compression filter function with which the prefiltered data will be correlated will next be determined. Consider an isolated point target at a slant range, R_s . The ground range to this target, R_g , is

$$R_g = (R_{go} + 32.8 \times M) \text{ ft} \quad , \quad (39)$$

where R_{go} is the ground range (in feet) to the near edge of the swath being mapped, 32.8 is the conversion factor from film scan to feet on the ground, and M is the number of the range cell in which the target lies (M equaling zero for the first range cell). The slant range and ground range are related by the equation

$$R_s = \left[h^2 + R_g^2 \right]^{1/2} \quad , \quad (40)$$

where h is the aircraft altitude.

As the aircraft flies past the point target, the phase of the return, ϕ , is equal to

$$\phi = \frac{4\pi R_s}{\lambda} \quad , \quad (41)$$

where R_s is the slant range to the target, and λ is the radar wavelength. The range R may be expressed as

$$R_s = \left[R_{so}^2 + X^2 \right]^{1/2} \quad , \quad (42)$$

where R_{so} is the slant range to the target when measured on a line perpendicular to the flightpath (i.e., at the point closest to the aircraft), and X is the along-track displacement of the aircraft from the point at which R_s is measured. As $R_{so} \gg X$, Equation (42) may be approximated as

$$R_s \approx R_{so} + \frac{X^2}{2R_{so}} \quad (43)$$

with a high degree of accuracy. Hence,

$$\phi = \frac{4\pi}{\lambda} \left[R_{so} + \frac{X^2}{2R_{so}} \right] = \phi_o + \frac{2\pi X^2}{\lambda R_{so}}, \quad (44)$$

where ϕ_o is a constant.

To Equation (44), the azimuth offset frequency (shown previously to be PRF/4/1.1, where the factor of 1.1 results from the digitizing process) has been added. Thus, the azimuth phase history of the signal presented to the azimuth compression filter is

$$\phi = \frac{4\pi}{\lambda} \frac{(0.826n)^2}{2(h^2 + (R_{so} + 32.8M)^2)^{1/2}} - 2\pi \cdot (0.227n) + \phi_o, \quad (45)$$

where

n = azimuth sample number, $n = 0$ occurring at $X = 0$

0.227 = azimuth offset frequency in cycles per foot on the ground after digitizing

0.826 = distance between samples in feet.

The azimuth compression reference function (ACF) which will compress the point target to the desired resolution is

$$ACF = \exp[j\phi] = \cos \phi + j \sin \phi \quad (46)$$

The value of ϕ_o for the reference is set to zero as it is an arbitrary constant. The value of N has been determined in Equation (38). The value n in Equation (45) will be stepped from $-N/2$ to $N/2$ for generation of the reference function. The compression is performed by the complex convolution of the data and the reference function, although the data quadrature component is always zero, and hence no multiplication is performed with this term.

The computed ACF will be weighted by a Taylor aperture function to reduce the azimuth sidelobes. (Recall that the broadening of the mainlobe of the compressed pulse has already been compensated for by the factor of 1.42 in the aperture length formula, Equation (31).) The Taylor aperture function has only real, positive coefficients. The product of the weighting function and the ACF will result in a function

$$ACF_{\text{weighted}} = A(n) \exp [j\phi] \quad , \quad (47)$$

where $A(n)_{\text{max}} = 1$ when $n = 0$, $-N/2 \leq n \leq N/2$.

The output of the azimuth compression convolution will be generated having 7.5-ft spacings, or equivalently at one-ninth of the input data rate. This will reduce the data rate and hence the number of calculations by a factor of nine, yet retains a sufficient number of data samples to preserve the processed resolution after detection.

Detection of the compressed data is accomplished by forming $I^2 + Q^2$ of the azimuth processed image; i.e., by squaring the real and quadrature components of the data and then summing them. Detection produces information which contains only magnitude information, the magnitude being proportional to the power of the return over the aperture length from a point target.

To obtain two looks in azimuth, the ACF will be twice the length as that used for one-look processing. The weighting function is applied in the same manner; however, twice as many sample functions are taken over the Taylor aperture function. The two looks are formed after azimuth compression and detection by passing the data through a post-detection filter. The postdetection filter's impulse response is equivalent to 30-ft resolution. This filter is formed by summing four consecutive azimuth compression filter outputs and dividing by four; i.e.,

$$E_{\text{Out}} = 0.25 \sum_{i=1}^4 E(i)_{\text{In}} \quad . \quad (48)$$

For every output of the azimuth compression filter, there will be one output of the post-detection filter.

For the azimuth compression, it has been shown that the phase of the ACF varies with range as shown in Equation (45), and that a new ACF can be computed for each range increment. Experience has shown, however, that satisfactory results may be achieved even if the phase difference between the signal and the ACF varies by as much as $\pm 22\text{-}1/2$ degrees. Hence,

$$\phi = \frac{4\pi R}{\lambda} = \phi_0 + \frac{2\pi x^2}{\lambda R_0} ,$$

$$\frac{d\phi}{dR_0} = -\frac{2\pi x^2}{\lambda R_0^2} dR_0 = \frac{\pi}{4} ,$$

$$x = \frac{1}{2} L_{\text{SYN}} = \frac{K\lambda R_0}{4W_A} ,$$

Therefore,

$$-\frac{2\pi}{\lambda R_0^2} \frac{K\lambda R_0^2}{4W_A} \Delta R = -\frac{K^2 \lambda \pi}{8W_A^2} \Delta R = \frac{\pi}{4} ,$$

$$|\Delta R| = \frac{2W_A^2}{K^2 \lambda} = \frac{11,520}{(\text{number of looks})^2} \text{ ft} . \quad (49)$$

For one look, $\Delta R = 11,520$ ft; and for two looks, $\Delta R = 2,880$ ft.

2. REMOVAL OF IMAGE SKEW

Because of such factors as aircraft across-track motion, antenna pointing errors, errors in scanning the data from the film, etc., the output data may be at a skew angle. The skew is corrected by the image distortion correction program.

The skew removal is accomplished by a "zero data" addition procedure. From the geometry shown in Figure 8, where ϕ is the skew angle, it is seen that the data must be rotated to orient the data's range vector with the vector perpendicular to the flightpath. To accomplish this, data points with magnitudes of zero are inserted at near and far range to form a rectangular data block, as illustrated in Figure 9. (The all-zero columns at near and far range are for computational convenience.)

The number of zeros added to each range return is given by the equation

$$NZ = NRG \sin (|\phi|) + 2 \quad , \quad (50)$$

where

NZ = the number of zeros added for skew correction

NRG = the number of ground range sweeps

$|\phi|$ = the absolute value of the skew angle.

The skew correction is calculated by

$$Y = AX + B \quad , \quad (51)$$

where

Y = the corrected ground range

X = the along-track distance relative to the patch being deskewed

$$A = \frac{NZ}{NRG} * \text{SIGN} (\phi)$$

$$B = \begin{array}{ll} 1 & \text{if SIGN } (\phi) \text{ is positive} \\ NZ & \text{if SIGN } (\phi) \text{ is negative.} \end{array}$$

Finally, it is noted that the number of zeros added to each range return must be an integer. If the number of zeros added to the i th range return is IZ_i , and the number of zeros added to the same return at far range is JZ_i , then

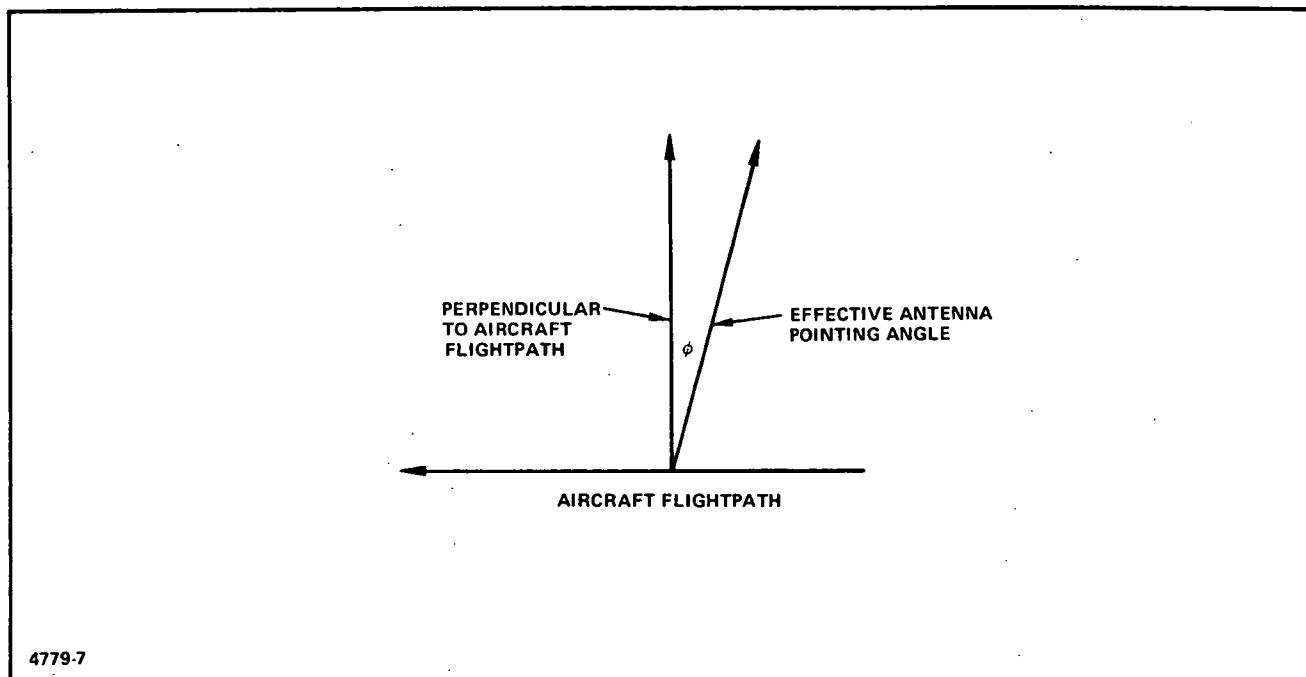


Figure 8 - Geometry of Data Skew

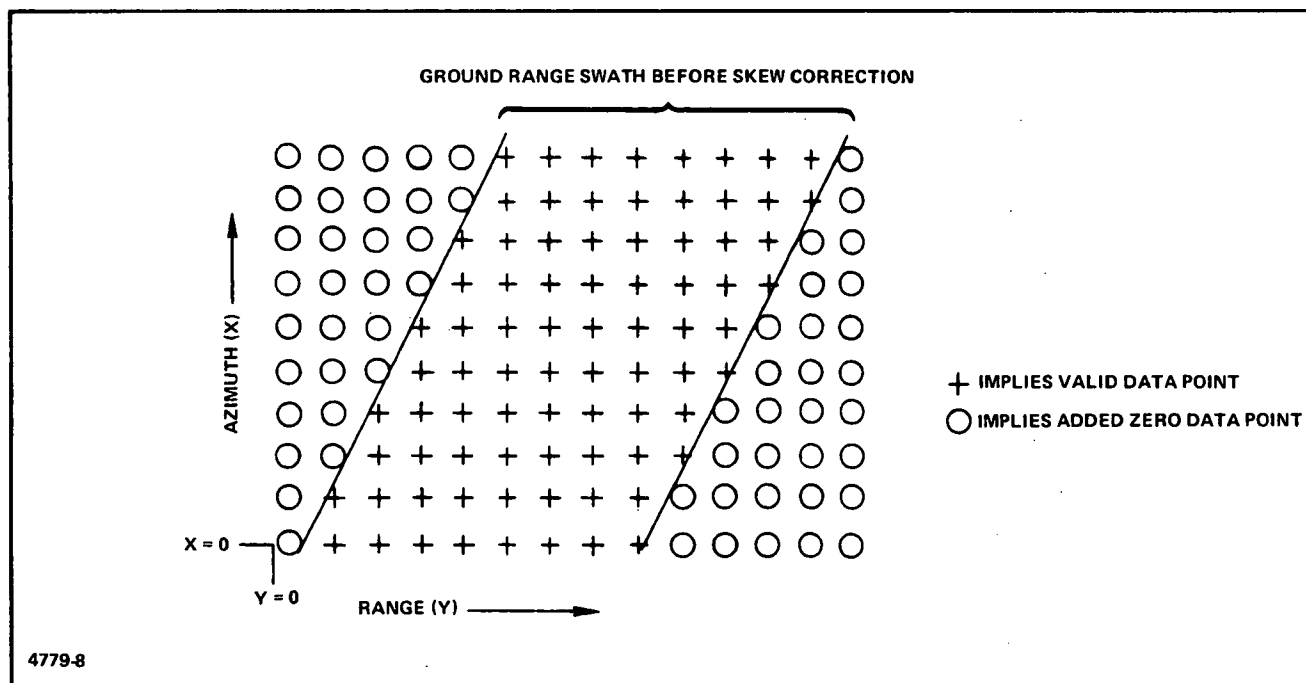


Figure 9 - Format of Data after Skew Correction

$$IZ_i = \left[(A)(i) + B \right]_{\text{ROUNDED}} \quad (52)$$

$$JZ_i = NZ - IZ_i \quad (53)$$

The placement of the zeros is illustrated in Figure 10.

3. SCALE FACTOR CORRECTION

Upon completion of the azimuth compression, the output data sample points may be spaced differently in range and azimuth. The image will consequently appear distorted because of the differing range and azimuth resolution. To compensate for this, a scale factor correction may be necessary.

Scale factor correction is accomplished by linear interpolation on the azimuth data. For example, assume that an azimuth sample was calculated every 12 feet, and that 30 feet was desired between samples in both dimensions. Then, to achieve azimuth samples spaced by 30 feet,

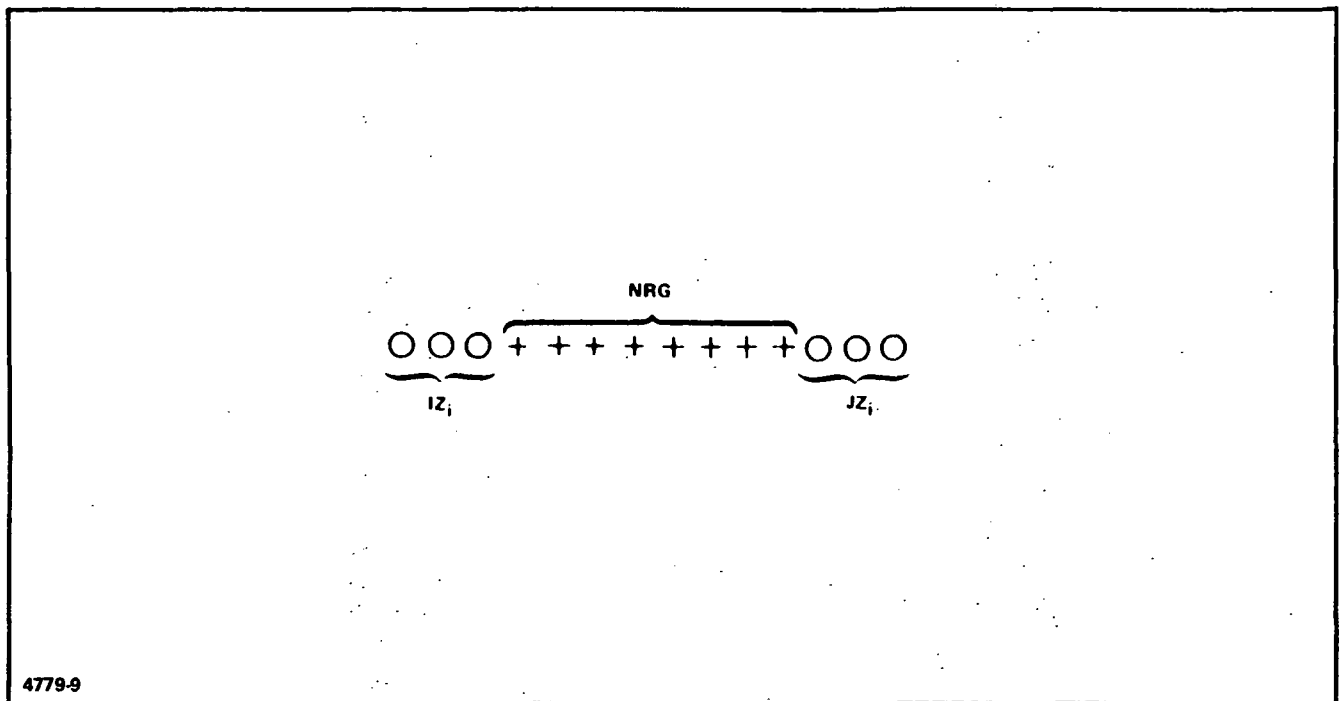


Figure 10 - Placement of Zero Data Points

$$Y_1' = Y_1$$

$$Y_2' = \frac{1}{4}(Y_3 + Y_4)$$

$$Y_3' = Y_6 \quad (54)$$

etc.

It is observed that data points Y_2 and Y_5 are not utilized in the foregoing calculation. Therefore, an increase in the processing rate is possible, because these points need not be calculated.

SECTION IV - CONCLUSIONS

The results of the geometric distortion analysis indicate that the distortions in AN/APQ-102A imagery are primarily the result of navigation system errors that are external to the radar system itself. These distortions can be rather high in magnitude (e.g., one percent), but have a low spatial frequency. As such, it is a relatively simple task to measure and remove the geometric distortion. Measurement is accomplished by comparing image distances (obtained from a map) between known ground features with good distances. Using this technique, the residual distortions were under 100 meters. Computer programs to measure and correct these distortions were delivered as part of the contract effort.

The major program effort consisted of generating a computer program to digitally process AN/APQ-102A phase history data. This program was checked out and validated at the customer's facility—thus providing a capability of processing subsequent AN/APQ-102A data without contractor support.

APPENDIX A -
TARGET SIMULATOR

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```
C      PROG-9-75  POINT TARGET GENERATOR
C
C      DIMENSION IDATA (8800),MTR1(27)
C
C      SCN=.2
C      BIS=.316
C      ALGF=.4342944819032
C      PI=3.1415926535897
C      ALAM=.1022
C      BW=.5*PI/180.
C      FPAL=4.*PI/ALAM
C      REWIND 2
C
C      200 CONTINUE
C      READ 98,MTR1
C      PRINT 101
C      PRINT 102
C      PRINT 99,MTR1
C      OUTPUT RECORD 1 ON TAPE
C
C      CALL TAPE R1(MTR1)
C
C      DAZ  DISTANCE PER AZIMUTH SAMPLE
C      DRG  DISTANCE PER RANGE  SAMPLE
C      AZOFS AZIMUTH OFFSET
C
C      HF  ALTITUDE IN FEET
C      R0  RANGE IN FEET
C      PHI0 PHASE ANGLE
C
C      READ 100,DAZ,DRG,AZOFS
C      PRINT 103,DAZ,DRG,AZOFS
C      READ 100,HF,R0,PHI0
C      PRINT 104,HF,R0,PHI0
C      201 CONTINUE
C
C      M  RG ELEMENT
C      N  AZ ELEMENT
```

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```
C      NRB  NUMBER OF RANGES
C
      READ 105,M,N,NRB
      IF(NRB) 198, 198, 199
198 CONTINUE
      CALL EXIT
199 CONTINUE
      PRINT 106,M,N,NRB
      IX=1
      XM=M
      XN=N
C      RG LOOP
C
      DO 202 I=1,NRB
      DO 203 I=1,8800
      IDATA(I)=0
203 CONTINUE
C      CALCULATE AZ INDEX LIMITS
C
      RS=SGRT(HF*HF+(R0+XM*DRG)**2)
      NAZ=SIN(BW)*RS/DAZ
      NAZ1=N-NAZ
      NAZ2=N+NAZ
C      LIMIT INDICES
C
      NAZ1=MAX(1,NAZ1)
      NAZ2=MIN(NAZ2,17600)
      PRINT 107,NAZ1,NAZ2
C      END OF BOOK KEEPING, DO THE CALCULATIONS
C
      JAZ=NAZ1
      AN=-NAZ
      AA=.5*FPAL*DAZ*DAZ/RS
      BB=-2.*PI*AZ0FS
      PRINT 109,AA,BB
      IY=C
      IF(NAZ1-8800)208,209,209
C      OUTPUT FIRST HALF OF AZ SWEEP
C
```

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```
209 CONTINUE
CALL TAPEW2 (IDATA,IX,IY)
IY=8800
JAZ=NAZ1-8800
208 CONTINUE
C    AZ LOOP
C
DO 204 IAZ=NAZ1,NAZ2
PHI=(AA*AN+PB)*AN+PHI0
C    TAKE C9S,ADD BIAS AND SCALE
C
T=SCN*C9S(PHI)+BIS
C    CONVERT TRANSMISSION TO DENSITY
C
D=ALGF*ALPG(1./T)
C    NOW SCALE TO 8 BITS
C
ID=D*128+.5
IDATA(JAZ)=ID
C
GO TO 197
PRINT 108,AN,PHI,T,D,ID
197 CONTINUE
AN=AN+1.
JAZ=JAZ+1
C
IF (JAZ-8800)204,204,205
205 CONTINUE
C    OUTPUT HALF OF AZ SWEEP
C
CALL TAPEW2(IDATA,IX,IY)
DO 206 I=1,8800
IDATA(I)=0
206 CONTINUE
IY=8800
JAZ=1
C
204 CONTINUE
210 CONTINUE
```

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```
C      OUTPUT SECOND HALF OF AZ SWEEP
C
      CALL TAPEW2(IDATA,IX,IY)
      IF(IY)212,212,211
212  CONTINUE
      IY=8800
      GO 213 I=1,8800
      IDATA(I)=0
213  CONTINUE
      GO TO 210
211  CONTINUE
C
      IX=IX+1
      XM=XM+1.
202  CONTINUE
C
      GO TO 201
98  FORMAT(8CA1)
99  FORMAT(6X80A1)
100 FORMAT (8E10.4)
101 FORMAT(6X14HPR8GRAM 9-75,20X30HG00DYEAR AEROSPACE CORPORATION,/)
102 FORMAT(6X22HP0INT TARGET GENERATOR,/)
103 FORMAT(6X5HDAZ =E12.5,5X5HDRG =E12.5,5X5HAZ0FS,E12.5,/)
104 FORMAT(6X5HWF =F12.1,5X5HRO =F12.1,5X5HPI0=F12.3,/)
105 FORMAT(16I5)
106 FORMAT(6X,3HM =I7,5X,3HM =I7,5X3HNRB,I7,/)
107 FORMAT(6X21HAZIMUTH SAMPLE LIMITS,2I10,/)
108 FORMAT(4F12.4,I5)
109 FORMAT(6X4HAA =E12.6,6X4HBB =E12.6,/)
      END
```

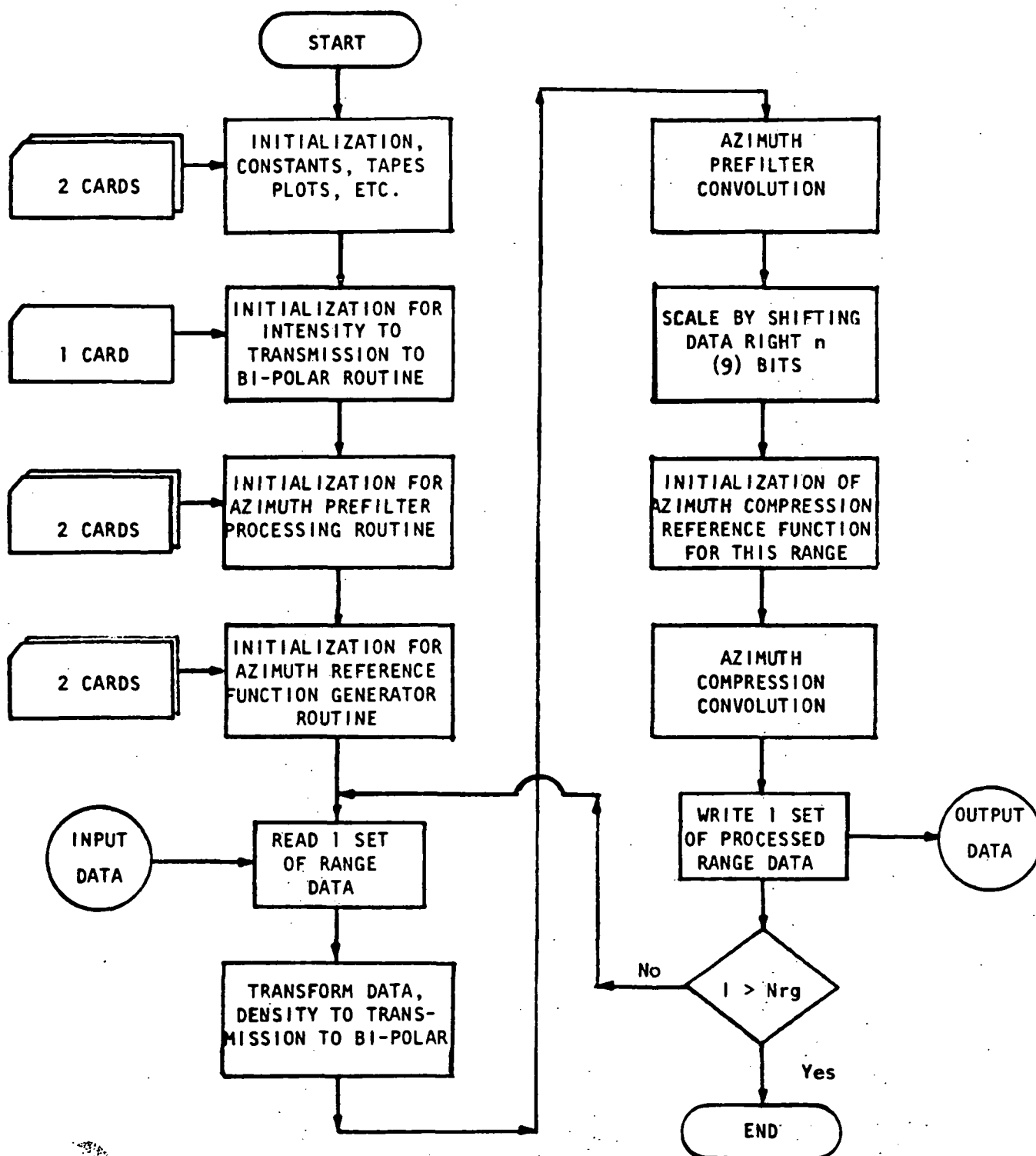
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```
SUBROUTINE TAPEF1(MTR1)
DIMENSION MTR1 (27)
C   THIS ROUTINE IS FOR WRITING RECORD 1  W I S S  MAG TAPE
C   FORMAT (27 CHARACTERS)
C   27 CHARACTERS OF WHICH 20 OR 22 ARE NEEDED
WRITE TAPE 2, MTR1
RETURN
END
```

```
SUBROUTINE TAPEW2(IDATA,IX,IY)
C   THIS ROUTINE IS FOR OUTPUT TO MAGNETIC
C   TAPE FOR THE SECOND AND SUBSEQUENT RECORDS
DIMENSION IDATA(8800)
WRITE TAPE 2, IDATA
RETURN
100 FORMAT(16,1X,40I3)
RETURN
END
```

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APPENDIX B -
AZIMUTH PROCESSING

AZIMUTH PROCESSING PROGRAM

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Card Input to the Azimuth Processing Program

Card 1 80 column description card.

Card 2 N number of data points/record.
(2 values) (Azimuth samples per range bin.)

NRG number of range bins to be processed.

Card 3 SCL = density represented by a value of 255.
(3 values) TMEAN = mean transmission for bipolar calculations.
 SCL2 = second scale to convert to integer.

These are for Initialization of the Density to
Transmission to Bipolar Routine.

Typical Data: SCL = 2 or 3, TMEAN = .38, SCL2 = 64 or 128.

Card 4 NLOOK = number of looks, 1 or 2.
(3 values) K = K in $\cos[2\pi K I/N]$, (see azimuth prefilter formula).
 NB = number of bits in the quantized output.

Card 5 PH10 = phase offset in degrees. (This is an arbitrary input.)
(1 value)

Cards 4 and 5 are for the azimuth prefilter reference function
generator routine.

Card 6 DAZ = distance per azimuth sample in feet.
(3 values) DRG = distance per range sample in feet.
 AZOFS = azimuth offset frequency in cycles/ft on ground.

Card 7 HF = altitude in feet.
(3 values) RO = range in feet.
 PH10 = phase angle in radians.

Cards 6 and 7 are for initialization of the compression
reference generator routine.

```
C      MAIN LINE      PROCESSING OF IMAGERY
C
C      DIMENSION IP(44), JD(45)
C      DIMENSION NN(20), RR(44)
C
C      DIMENSION ID(17600)
C      DIMENSION KD(931)
C      DIMENSION ICR(930), ICQ(930)
C
C      EQUIVALENCE (ID(1),JD(44))
C      EQUIVALENCE (KD(931),ID(1))
C      N = 17600
C      JT=1
C      IT=2
C      TAPE 2 IN, TAPE 1 BUT
200  CONTINUE
C      REWIND IT
C      REWIND JT
C      AN = 80 CBL DESCRIPTION
C      READ 99,AN
C      PRINT 101
C      PRINT 98,NN
C      READ 100,N,NRG
C      PRINT 102,N,NRG
C      NT=N
C      K = C
C      CALL DNTBBP (ID,K)
C      CALL REFGFN (IR,NPR)
C
C      NLBBK = 1
C      IF(NPR-22) 220, 220, 221
220  CONTINUE
C      NLBBK = 2
221  CONTINUE
C      M = -NLBBK
C      CALL CMPREF (ICR,ICQ,M)
C
C      LOOP ON RG
C
C
```

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```
      MAX=0
      DO 201 MRG=1,NRG
      N = NT
      CALL TAPEIN (ID,NT)
      K = N
      CALL DNTREP (ID,K)
      CALL PRINTD (ID,N)
C
      NP = N
      CALL AZPRF (ID,IR,N,NPR,JD,NP)
C
C      SHIFT DATA BY 9 BITS
C
      DO 207 I = 1, NP
      JD(I) = JD(I)/512
207  CONTINUE
      CALL PRINTD (JD,NP)
      CALL PLOTD(JD,NP)
C
      M = MRG
      CALL CMPREF (ICR,ICQ,M)
      NR = M
      CALL PRINTD (ICR,M)
      CALL PRINTD (ICQ,M)
C
      NS = 9
      CALL AZCOMP (JD,ICR,ICQ,NP,NR,NS,KD)
      N = NP/NS
      GO TO (224,222), NLOOK
222  CONTINUE
C
C      TWO LOOK CALCULATIONS
C
      NP = N-3
      DO 223 I = 1, NP
      KD(I) = KD(I)+KD(I+1)+KD(I+2)+KD(I+3)
      223  CONTINUE
      N = NP
      224  CONTINUE
```

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```
C      CALL PRINTD (KD,N)
      DO 206 I=1,N
      IF (MAX-KD(I))205,206,206
205  CONTINUE
      MAX=KD(I)
      PRINT 104,NRG,I,MAX
206  CONTINUE
      NP=N+1
      DO 203 I=NP,NT
      KD(I)=1
203  CONTINUE
      CALL TAPEOUT(KD,NT)
201  CONTINUE
      CALL PLOTD (KD,N)
      GO TO 200
      CALL PLOTD (ID,K)
      WRITE TAPE JT, (JD(I),I=1,K)
      98  FORMAT (6X20A4,/)
      99  FORMAT (20A4)
      100 FORMAT (8E10.4)
      101 FORMAT (36X35HIMAGE PROCESSING G.A.C. PR0G 9-75,/)
      102 FORMAT(6X19HNUMBER OF SAMPLES =,I7,5X22HNUMBER OF RANGE BINS =I7
      1,/)
      104 FORMAT (I10,2X10I9)
      END
```

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```
C      SUBROUTINE DNTRAP (ID,M)
C      DENSITY TO TRANSMISSION TO BI POLAR
C      DIMENSION ID(17600)
C      DIMENSION JD(256)
C      IF(M) 200, 200, 210
200 CONTINUE
C      SCL   = DENSITY REPRESENTED BY A VALUE OF 255
C      TMEAN = MEAN TRANSMISSION FOR BIPOLAR CALCULATIONS
C      SCL2  = SECND SCALE TO CONVERT TO INTEGER
C      TYPICAL DATA: SCL=2 OR 3, TMEAN=.38, SCL2=64 OR 128
C
      READ 100, SCL, TMEAN, SCL2
      PRINT 101
      PRINT 102, SCL, TMEAN, SCL2
      PRINT 103
      SCL = SCL/256.
      DO 201 I = 1, 256
        K = I-1
        X = K
        X = X*SCL
        X = 10.**(-X)
        X = X-TMEAN
        JD(I) = X * SCL2
      PRINT 104, K, JD(I)
201 CONTINUE
      RETURN
C
210 CONTINUE
      N = M
      BIAS = 0.
      DO 211 I = 1, N
        K = ID(I)+1
        IF(K) 212, 212, 213
213 CONTINUE
        IF(K-255) 214, 214, 212
```

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```
212 CONTINUE
    PRINT 105, ID(I)
214 CONTINUE
    ID(I) = JD(K)
    X = ID(I)
    BIAS = BIAS+X
211 CONTINUE
    X = N
    BIAS = BIAS/X
    PRINT 106, BIAS
    RETURN
```

C

```
100 FORMAT (8E10.4)
101 FORMAT (////////,6X40HDENSITY TO TRANSMISSION TO BI POLAR DATA,/)
102 FORMAT (6X,5HSCL =,F10.4,5X5HTMEAN,F10.4,5X5HSCL2=,F10.4,/)
103 FORMAT (25X7HDATA IN,10X6HRESULT,/)
104 FORMAT (25X15,10X15)
105 FORMAT (6X33H*** INPUT DATA OUT OF RANGE ***,15)
106 FORMAT (6X31HAVERAGE BIAS FOR THIS RANGE WAS,F10.4)
    END
```

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```

C      SUBROUTINE REEGEN (IR,N)
C      AZIMUTH PREFILTER REFERENCE FUNCTION GENERATOR
C      TWO DATA CARDS REQUIRED
C
C      DIMENSION IR(44)
C      DIMENSION RR(44)
C
C      NL00K = NUMBER OF LOOKS
C      K      = K IN CBS(2PI K I/N)
C      NB     = NUMBER OF BITS IN THE QUANTIZED OUTPUT
C
C      PHIO = PHASE OFFSET
C
C      PI = 3.1415926535897
C      READ 103, NL00K, K, NB
C      PRINT 104, NL00K, K, NB
C      READ 100, PHIO
C      PRINT 105, PHIO
C      SC = (2.**NB)-1.
C      N = 22
C      GO TO (201,202), NL00K
201  CONTINUE
C      N = 44
202  CONTINUE
C      XL = N
C      PRINT 106
C      XMIN = 0.
C      XMAX = N-1
C      A = 40.
C      NB = 6
C      X = 0.
C      CALL TAYLOR (XMIN,XMAX,A,NB,X,WTN,0)
C      DO 203 I = 1, N
C      A = (I-1)*K
C      A = 2.*PI*A/XN+PHIO
C      X = I-1
C      CALL TAYLOR (XMIN,XMAX,A,NB,X,WTN,1)
C      RR(I) = WTN*CBS(A)

```

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```
203 CONTINUE
C
C   PUT AMPLITUDE WEIGHTING HERE
C
      DB 204, I = 1, N
      P5 = .5
      IF(RR(I)) 205, 205, 206
205 CONTINUE
      P5 = -.5
206 CONTINUE
      IR(I) = RR(I)*SC+P5
      PRINT 107, I, IR(I)
204 CONTINUE
      RETURN
100 FORMAT (RE10.4)
103 FORMAT (16I5)
104 FORMAT (6X7HNLBPK, //, I3, 5X3HK, //, I3, 5X4HNB, //, I3, /)
105 FORMAT (6X7HPHIS, //, F10.4, /)
106 FORMAT (//, 6X9HREFERENCE, 10X1HI, 10X1HR, /)
107 FORMAT (15X2I11)
      END
```

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```
C      SUBROUTINE AZPRF (ID,IR,N,NPR,JD,NP)
      AZIMUTH PREFILTER WALLBPS DATA
      DIMENSION IR(44), JD(45)
      DIMENSION ID(17600)
C
      NP=N-NPR
      DO 202 I=1,NP
      IS=0
      DO 203 J=1,NPR
      K = I+J-1
      IS=ID(K)*IR(J)+IS
203  CONTINUE
      JD(I)=IS
202  CONTINUE
      RETURN
      END
```

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```

C      SUBROUTINE CMPREF (IR,IQ,M)
C      COMPRESSION REFERENCE GENERATOR
C      DIMENSION IR(930),IQ(930)
C
C      M = -1 OR -2 FOR INITIALIZATION  ABS(M) = NLOOKS
C
C      M RETURNED AS NUMBER OF POINTS IN THE REF
C
C      IF(M) 200, 210, 210
200  CONTINUE
      PI = 3.1415926535897
      ALAM = .1022
      WA = 30.
      SNF = .88
      TWF = 1.42
      XK = SNF*TWF
      XLOOK = IABS(M)
      FPAL = 4.*PI/ALAM
C
C
C      DAZ = DISTANCE PER AZIMUTH SAMPLE
C      DRG = DISTANCE PER RANGE SAMPLE
C      AZOFS = AZIMUTH OFFSET
C
C      HF = ALTITUDE IN FEET
C      RO = RANGE IN FEET
C      PHI0 = PHASE ANGLE
C
C
C      NDBC = DB DOWN FOR TAYLOR WEIGHTING (40)
C      NBAR = NBAR FOR TAYLOR WEIGHTING (6)
C      NBITS = NUMBER OF BITS IN REF FUNCTIONS 6,7,8
C
C      READ 100, DAZ, DRG, AZOFS
C      PRINT 103, DAZ, DRG, AZOFS
C      READ 100, HF, RO, PHI0
C      PRINT 104, HF, RO, PHI0
C      NDBC = 40
C      NBAR = 6

```

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```
NRITS = 8
PRINT 105, NDBD, NBAR, NRITS
DBD = NDBD
SC = (2.**NRITS)-1.
PN = .5*XK*ALAM/(WA*DAZ)
FN = PN*XL0RK
201 CONTINUE
RETURN
210 CONTINUE
XM = M
RS = SGRT(HF*HF+(R0+XM*DRG)**2)
NAZ = RS*PN/2.**.5
AN = -NAZ
N = NAZ+NAZ+1
M = N
XMIN = -NAZ
XMAX = NAZ
AA = .5*FPAL*DAZ*DAZ/RS
BB = -2.*PI*A79FS
PRINT 106, AA, BB
CALL TAYLER (XMIN,XMAX,DBD,NBAR,AN,AMP,0)
DO 211 I = 1, N
CALL TAYLER (XMIN,XMAX,DBD,NBAR,AN,AMP,1)
PHI = (AA*AN+BB)*AN+PHI0
AN = AN+1.
R = AMP*SC*COS(PHI)
G = AMP*SC*SIN(PHI)
IR(I) = R
IC(I) = G
211 CONTINUE
RETURN
100 FORMAT (8E10.4)
101 FORMAT (I10,4E12.6,2I10)
102 FORMAT(16I5)
103 FORMAT (6X5HDAZ,.,E12.5,5X5HDRG,.,E12.5,5X5HAZ0FS,E12.5,/)
104 FORMAT (6X5HHF,.,F12.1,5X5HR0,.,F12.1,5X5HPI0,.,F12.3,/)
105 FORMAT (6X6HNDDBD,.,I5,5X6HNBAR,.,I5,5X6HNBITS,.,I5,/)
106 FORMAT (6X4HAA,.,E12.5,5X4HBB,.,E12.5,/)
END
```

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```

C      SUBROUTINE AZCOMP (ID,IR,IQ,N,NR,NS,JD)
C      AZIMUTH COMPRESSION FILTER
C
C      DIMENSION ID(17600)
C      DIMENSION JD(45)
C      DIMENSION IR(930),IQ(930)
C      N = NUMBER OF POINTS IN THE DATA
C      NR = NUMBER OF POINTS IN THE REFERENCE
C      NS = NUMBER OF POINTS FROM OUTPUT SAMPLE TO NEXT OUTPUT SAMPLE
C
C      ID IS DATA
C      JD IS OUTPUT
C      IR IS REAL REF CHANNEL
C      IQ IS QUAD REF CHANNEL
C
C      N = N-NR
C      K = 1
C      DO 200 I = 1, N, NS
C      ISR = 0
C      ISQ = 0
C      DO 201 J = 1, NR
C      L = J+I-1
C      JR = IR(J)*ID(L)/256
C      JQ = IQ(J)*ID(L)/256
C      ISR = ISR+JR
C      ISQ = ISQ+JQ
201  CONTINUE
C      KK = 128
C      KK = 64
C      ISQ = ISQ/KK
C      ISR = ISR/KK
C      IS = ISR*ISR+ISQ*ISQ
C      JD(K)=IS
C      K = K+1
200  CONTINUE
C      RETURN
C      END

```

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```

C      SUBROUTINE TAYLOR (XMIN,XMAX,A,NB,X,ANS,JOB)
C      THIS SUBROUTINE CALCULATES THE TAYLOR APERTURE
C      XMIN    XMAX-XMIN = RANGE OF APERTURE
C      XMAX
C      A      = DB DOWN OF FIRST SIDELobe IN TAYLOR ANTENNA PATTERN
C      NB      = N-PAR (TAYLOR'S CONSTANT)
C      X      = VALUE AT WHICH ONE POINT OF APERTURE IS WANTED
C      ANS     = THE RETURNED ANSWER
C      JOB     = 0 THIS IS A NEW XMIN,XMAX,A AND NB DATA SET
C              = 1 USE PREVIOUS XMIN,XMAX,A AND NB DATA CALCULATIONS
C
C      DIMENSION F(20), C(10), FF(2)
C      EQUIVALENCE (FF(2),F(1))
C
C      IF (JOB) 11, 11, 12
11  CONTINUE
      D = XMAX-XMIN
      PI = 3.1415926535897
      TPI = 2.*PI
      F(0) = 1.
      DO 10 I = 1, 20
      ARG = I
      F(I) = F(I-1)*ARG
10  CONTINUE
      AA = 10.**(ABS(A)/20.)
      CALL ARCSH (AA,ETA)
      AA = ETA/PI
      A2 = AA*AA
      ENB = NB
      NBM = NB-1
      SIG = ENB/SQRT(A2+(ENB-.5)**2)
      DO 20 N = 1, NBM
      EN = N
      EN2 = EN*EN
      S = 1.
      DO 30 M = 1, NBM
      EM = M
      ZM = SIG*SQRT(A2+(EM-.5)**2)
      S = S*(1.-EN2/(ZM*ZM))

```

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```
30 CONTINUE
  C(N) = S * F(NBM) * F(NBM) / (F(NBM+N) * F(NBM-N))
20 CONTINUE
12 CONTINUE
  F = (X - XMIN) / D * TPI - PI
  ANS = C
  DO 40 N = 1, NBM
    EN = N
    ANS = ANS + C(N) * CBS(EN * P)
40 CONTINUE
  ANS = 1. + 2. * ANS
  RETURN
```

C

```
  PRINT 100, A, NB
  PRINT 103, AA, SIG
  PRINT 101, N, C(N)
  PRINT 102
100 FORMAT (5X17H SUBROUTINE TAYLOR, // 5X17H FIRST SIDELobe = , F6.1,
1 3H DE, 10X8H -BAR = , 12, // 10X12H COEFFICIENTS)
101 FORMAT (5X15, 5X F15.8)
102 FORMAT (1H1)
103 FORMAT (18X2H AA, 17X3H SIG, / 2(5X E15.8), /)
  END
```

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C SUBROUTINE ARCSH (U,A)
 U2 = U*U
 IF (U2-1.) 11, 11, 12
12 CONTINUE
 A = ALOG(U+SGRT(U2-1.))
 RETURN
11 CONTINUE
 A = 0.
 PRINT 101
 RETURN
101 FORMAT (1H0,5X56H*** TAKING ARCSH OF A NUMBER LESS THAN 1 IMPOSSI
1BLE ***,/)
 END

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APPENDIX C -
DISTORTION ANALYSIS

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1.    DOUBLE PRECISION EX(512),EY(512)
2.    DIMENSION IBUF(1000)
3.    DOUBLE PRECISION X(512),Y(512),P(512),Q(512),A,B,C,E(512),D,F,G,X1
4.    1(512),M,AL,A1,A2,A3,A4,          V,V1,A3(20),XE(512),YE(512),C1,Y1(
5.    2512)
6.    DIMENSION AA(16),AA1(20),AA2(20),AA3(20),AA4(20),NE(20),CA(20),CB(
7.    120)
8.    DIMENSION ALPHA(2,512)
9.    COMMON N,PMIN,CMIN,SCPLT,SCEROR
10.   C   X AND Y ARE THE TRACK AND RANGE COORDINATES ON THE IMAGERY,
11.   C   RESPECTIVELY. R AND S ARE THE MAP POINTS AND SHOULD BE WITHIN 45
12.   C   DEGREES OF THE IMAGERY POINTS. N1 AND N2 SHOULD LIE APPROXIMATELY
13.   C   IN THE TRACK DIRECTION WITH N1 TO THE LEFT OF N2.
14.   C   CALL PLOTS(IBUF,1000,7)
15.   C   PLOT TAPE ON 183
16.   READ(1,55)AA1,AA2,AA3,AA4
17.   55 FORMAT(20A4)
18.   25 READ(1,1)N,N1,N2,AA
19.   1 FORMAT(3I5,16A4)
20.   IF(N)20,20,30
21.   30 CONTINUE
22.   C   SCALE OF PLOT AND SCALE OF ERRORS
23.   READ(1,3)SCPLT,SCEROR
24.   DO 2 I=1,N
25.   READ(1,211) P(I),Q(I)
26.   211 FORMAT(3F10.2)
27.   2 READ(1,345)X(I),Y(I),ALPHA(1,I),ALPHA(2,I)
28.   C
29.   C
30.   C   CHANGE FORMAT CARD
31.   3 FORMAT(2F10.3)
32.   345 FORMAT(2F10.3,A4,A4)
33.   C   ROTATION OF MAP SECTION
34.   A=DATAN((Y(N2)-Y(N1))/(X(N2)-X(N1)))
35.   B=DATAN((G(N2)-G(N1))/(P(N2)-P(N1)))
36.   A=A-B
37.   1003 ANGLE=A
38.   ADEG=57.29578*A
39.   DO 4 I=1,N
40.   B=P(I)
41.   P(I)=P(I)*DCOS(-A)+Q(I)*DSIN(-A)
42.   Q(I)=Q(I)*(DCOS(-A))-B*(DSIN(-A))
43.   CALL LSF(1,N,Y,X,Q,P,A,B)
44.   DO 5 I=1,N
45.   5 E(I)=A+Y(I)+B-Q(I)
46.   CALL LSF(1,N,P,Y,E,2,A,B)
47.   A=DATAN(A)
48.   ADEG=ADEG+57.29578*A
49.   WRITE(3,800)ADEG
50.   800 FORMAT(1X,'ANGULAR ROTATION =',F10.4,' DEGREES')
51.   DO 6 I= 1,N
52.   B=P(I)
53.   P(I)=P(I)*(DCOS(-A))+Q(I)*(DSIN(-A))

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54.      6 D(I)=Q(I)*DCOS(A)-B*DSIN(A)
55.      C      PLOT SCALING SECTION
56.          PMIN=10.E10
57.          QMIN=10.E10
58.          DO 200 I=1,N
59.              IF(P(I).LT.PMIN)PMIN=P(I)
60.          200 IF(Q(I).LT.QMIN)QMIN=Q(I)
61.          CALL PLOT(0.,1.,3)
62.          CALL LSF(1,N,X,Y,P,Q,A,B)
63.          A1=A
64.      1005 BY=B
65.          AL=B
66.          CALL LSF(1,N,X,Y,P,Q,A,B)
67.      C      TEMPORARY SECTION TO MEASURE IMAGERY DISTORTION AFTER CORRECT ALIGNMENT
68.          A2=(A1+A)/2.
69.          DO 51 I=1,N
70.              X1(I)=A2*X(I)
71.          51 Y1(I)=A2*Y(I)
72.          A3=0.
73.          A4=0.
74.          DO 52 I=1,N
75.              A3=A3+X1(I)-P(I)
76.          52 A4=A4+Y1(I)-Q(I)
77.              A3=A3/N
78.              A4=A4/N
79.          DO 53 I=1,N
80.              X1(I)=X1(I)-A3
81.          53 Y1(I)=Y1(I)-A4
82.          CALL MCP(X1,Y1,P,Q,N,AQ,V,V1,VE,XE,YE,C1,M)
83.          KK=0
84.          WRITE(3,56)AA1
85.      56 FORMAT(1H1///20X,20A4///)
86.          CALL EPLT(P,Q,XE,YE,EX,EY,AA1,AA)
87.          GO TO 54
88.      57 CONTINUE
89.          DO 70 I=1,N
90.              X1(I)=A*X(I)
91.          70 Y1(I)=A1*Y(I)
92.          A3=0.
93.          A4=0.
94.          DO 705 I=1,N
95.              A3=A3+X1(I)-P(I)
96.          705 A4=A4+Y1(I)-Q(I)
97.              A3=A3/N
98.              A4=A4/N
99.          DO 710 I=1,N
100.             X1(I)=X1(I)-A3
101.          710 Y1(I)=Y1(I)-A4
102.          CALL MCP(X1,Y1,P,Q,N,AQ,V,V1,VE,XE,YE,C1,M)
103.          WRITE(3,56)AA2
104.          CALL EPLT(P,Q,XE,YE,EX,EY,AA2,AA)
105.          GO TO 54
106.      67 CONTINUE

```

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107.      C=.0005
108.      D=0.
109.      DO 7 I=1,N
110.          E(I)=A*X(I)+B-P(I)
111.      7 D=D+DABS(E(I))
112.      AL=C
113.      F=0.
114.      DO 8 I=1,N
115.      8 X1(I)=X(I)+AL*Y(I)
116.          CALL LSF(1,N,X1,Y,P,D,A,B)
117.      DO 9 I=1,N
118.      9 F=F+DABS(A*X1(I)+B-P(I))
119.          IF(F=D)11,11,10
120.      10 AL=.AL
121.      C=C
122.      11 AL=AL+C
123.      DO 12 I=1,N
124.      12 X1(I)=X(I)+AL*Y(I)
125.      1006 BX=B
126.          CALL LSF(1,N,X1,Y,P,D,A,B)
127.      G=0.
128.      DO 13 I=1,N
129.      13 G=G+DABS(A*X1(I)+B-P(I))
130.          IF(G=F)16,16,14
131.      16 F=G
132.      GO TO 11
133.      14 AL=AL+C
134.      C      TEMPORARY SECTION 2
135.      A=C.
136.      A3=C.
137.      DO 71 I=1,N
138.      71 Y1(I)=A2*Y(I)
139.      X1(I)=A2*X(I)
140.      71 X1(I)=X1(I)+AL*Y1(I)
141.      DO 72 I=1,N
142.      72 A3=A3+X1(I)-P(I)
143.      A=A+A*Y1(I)-Q(I)
144.      A3=A3/4
145.      A=A/4
146.      DO 73 I=1,N
147.      73 Y1(I)=Y1(I)-A3
148.      CALL MCP(X1,Y1,P,D,N,AG,V,V1,VE,XE,YE,C1,M)
149.      WRITE(3,56)AA3
150.      CALL EPL0T(P,D,XE,YE,EX,EY,AA3,AA)
151.      GO TO 54
152.      68 CONTINUE
153.      DO 74 I=1,N
154.      74 X1(I)=X(I)+AL*Y(I)
155.      X1(I)=A*X1(I)
156.      74 Y1(I)=A1*Y(I)
157.      A3=0.
158.      A4=0.
159.

```

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160.      DO 713 I=1,N
161.          A3=A3+X1(I)*P(I)
162.      713 A4=A4+Y1(I)*Q(I)
163.          A3=A3/N
164.          A4=A4/N
165.      DO 714 I=1,N
166.          X1(I)=X1(I)-A3
167.      714 Y1(I)=Y1(I)-A4
168.          CALL HCR(X1,Y1,P,Q,N,AG,V,V1,VE,XE,YE,C1,M)
169.          WRITE(3,56)AAA
170.          CALL EPL0T(P,Q,XE,YE,EX,EY,AAA,AA)
171.          GO TO 54
172.      69 CONTINUE
173.          AL=AL*(+57.296)
174.      C      SCALE CARDS GO HERE
175.          WRITE(3,35)AA
176.          WRITE(3,15)A,A1,AL
177.          15 FORMAT(10X,'THE TRACK DIRECTION SCALE FACTOR IS 1:',F12.4,' , THE
178.              RANGE DIRECTION',10X,'SCALE FACTOR IS 1:',F12.4,' , THE SHEAR IS '
179.              2,F6.2,' DEGREES'////)
180.          35 FORMAT(10X,16A4)
181.          GO TO 25
182.      20 CONTINUE
183.      C      STANDARD WRITE SECTION
184.          GO TO 75
185.      54 KK=KK+1
186.          WRITE(3,58)
187.          58 FORMAT(28X,'TABLE I = RESIDUAL ERRORS'//17X,'POINT NUMBER',10X,'TR
188.              ACK ERROR',10X,'RANGE ERROR'//)
189.          WRITE(3,60)(I,XE(I),YE(I),ALPHA(1,I),ALPHA(2,I),I=1,N)
190.      60 FORMAT(18X,13,16X,F10.2,11X,F10.2,4X,A4,A4)
191.          SUM=0.
192.          SUMY=0.
193.          DO 21 I=1,N
194.              SUM=SUM+XE(I)*XE(I)
195.          21 SUMY=SUMY+YE(I)*YE(I)
196.              SUMY=SUMY/N
197.              SUM=SUM/N
198.              SUM=SQRT(SUM)
199.              SUMY=SQRT(SUMY)
200.              WRITE(3,22)SUM,SUMY
201.          22 FORMAT(5X,'X VARIANCE = ',F10.4,'Y VARIANCE = ',F10.4)
202.          GO TO(57,67,68,69,75),KK
203.      75 CONTINUE
204.          CALL PLOT(12.0,0.0,999)
205.          CALL EXIT
206.          END

```

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```
19:35 APR 03, '75
1.      SUBROUTINE LSF(J,M,X,Y,P,Q,A,B)
2.      REAL*8 X(1),Y(1),P(1),Q(1),S,R,T,U,A,B
3.      C   THIS SECTION DOES A LEAST SQUARES FIT OF M POINTS, STARTING FROM
4.      C   THE JTH POINT IN X AND P
5.      K=J+M-1
6.      A=0.
7.      S=0.
8.      R=0.
9.      B=0.
10.     T=0.0
11.     U=0.0
12.     DO 1 I=J,K
13.       S=S+X(I)
14.       R=R+P(I)
15.       T=T+X(I)*X(I)
16.       1 U=U+X(I)*P(I)
17.       A=(U-((S*R)/M))/(T-((S*S)/M))
18.       B=(R-A*S)/M
19.     RETURN
20.     END
```

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```

                                19:35 APR 03, '75
1.      SUBROUTINE EPLUT(P,Q,XE,YE,EX,EY,AAA,AA)
2.      DOUBLE PRECISION P(1),Q(1),XE(1),YE(1),EX(1),EY(1)
3.      DIMENSION AAA(1),AA(1)
4.      COMMON N,PMIN,QMIN,SCPLT,SCEROR
5.      CALL SYMBOL(0.,0.,.14,AAA,90.,80)
6.      XMAX=0.
7.      CALL PLOT(0.5,0.,-3)
8.      DO 1 I=1,N
9.      XPAGE=(P(I)-PMIN)/SCPLT
10.     YPAGE=(Q(I)-QMIN)/SCPLT
11.     IF(XPAGE.GT.XMAX)XMAX=XPAGE
12.     CALL SYMBOL(XPAGE,YPAGE,.07,3,0.,-1)
13.     XPAGE=XPAGE-XE(I)/SCEROR
14.     IF(XPAGE.GT.XMAX)XMAX=XPAGE
15.     YPAGE=YPAGE-YE(I)/SCEROR
16.     1 CALL SYMBOL(XPAGE,YPAGE,.07,1,0.,-2)
17.     XPAGE=XPAGE+.5
18.     ILIM=XPAGE
19.     XPAGE=ILIM+.5
20.     CALL SYMBOL(8.000,1.4,.140,AA,90.,64)
21.     XPAGE=XPAGE+12.
22.     CALL PLOT(XPAGE,0.,-3)
23.     RETURN
24.     END

```

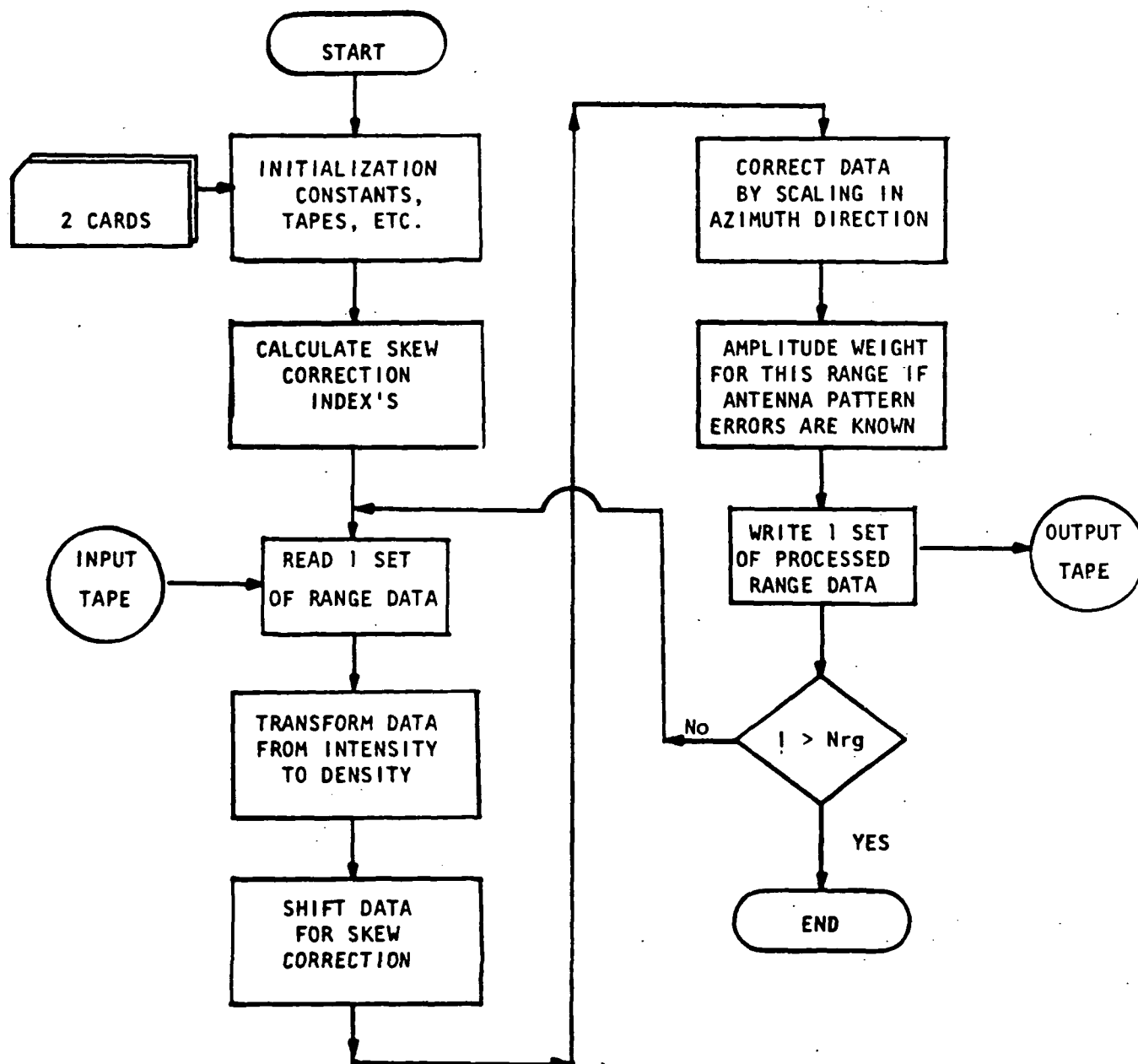
```

                                19:35 APR 03, '75
1.      SUBROUTINE MCP(X1,Y1,P,Q,N,AG,V,V1,VE,XE,YE,C1,M)
2.      REAL*8 X1(1),Y1(1),P(1),Q(1),AG(1),VE(1),V,V1,XE(1),YE(1)
3.      C      THIS SUBROUTINE COMPUTES THE HISTOGRAM OF THE LENGTH DIFFERENCES BETWEEN
4.      C      THE RADAR AND TAP POINTS, AS WELL AS THE ABSOLUTE ERRORS AND CEP(C1)
5.      DO 3 I=1,20
6.      3 AG(I)=0.
7.      DO 4 I=1,N
8.      XE(I)=X1(I)-P(I)
9.      4 YE(I)=Y1(I)-Q(I)
10.     DO 5 I=1,N
11.     AG(1)=AG(1)+DABS(XE(I))
12.     5 AG(2)=AG(2)+DABS(YE(I))
13.     AG(1)=AG(1)/N
14.     AG(2)=AG(2)/N
15.     RETURN
16.     END

```

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APPENDIX D -
IMAGE DISTORTION CORRECTION

IMAGE DISTORTION CORRECTION PROGRAM

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Card Input to the Image Distortion Correction program.

Card 1 ITN = Tape unit input.
(4 values) ITO = Tape unit output.
 NAZ = Number of azimuth samples per record.
 NRG = Number of range elements.

Card 2 SAZ = Azimuth scale.
(3 values) SRG = Range scale.
 SKEW = Skew or shear angle in degrees.

```
C      MAIN LINE PART TWO  INTENSITY TO DENSITY,
C      SKEW REMOVE ROUTINE, SCALE IN AZIMUTH, AND WEIGHT IN RANGE
C
      DIMENSION ID(2100)
      DIMENSION NN(20)
      DIMENSION JD(2100)
C
      PI = 3.1415926535897
200  CONTINUE
      READ 99, NN
      PRINT 101
      PRINT 102
      PRINT 98, NN
C
C      ITN  TAPE UNIT INPUT
C      ITS  TAPE UNIT OUTPUT
C      NAZ  NUMBER OF AZIMUTH SAMPLES PER RECORD
C      NRG  NUMBER OF RANGE ELEMENTS
C
      READ 103, ITN, ITS, NAZ, NRG
      PRINT 104, ITN, ITS, NAZ, NRG
C
C      SAZ  AZIMUTH SCALE
C      SRG  RANGE SCALE
C      SKEW SKEW OR SHEAR ANGLE
C
      READ 100, SAZ, SRG, SKEW
      PRINT 105, SAZ, SRG, SKEW
      REWIND ITS
      REWIND ITN
      RATIO = SAZ/SRG
      AZN = NAZ
      AZN = AZN*RATIO
      RGN = NRG
      NZ = ABS(RGN*SIN(SKEW*PI/180.))
      NAZP = AZN
      NAZP = NAZP+NZ
      BR=NZ
      AA=NRG
```

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```
      AA=-BB/AA
      IF (SKEW)220,220,221
220  CONTINUE
      BB=1.
      AA=-AA
221  CONTINUE
      CALL INTDEN (ID,-1)
      NZ = NZ+2
C      ONE ON EACH SIDE ALWAYS
      DO 201 IRG = 1, NRG
      READ TAPE ITN, (ID(K),K=1,NAZ)
      CALL INTDEN(ID,NAZ)
      XIRG=IRG
      IZ=AA*XIRG+BB+.5
      IZ = MAX(IZ,1)
      JZ=NZ-IZ
      K=1
      DO 222 II=1,IZ
      JD(K)=0
      K=K+1
222  CONTINUE
      DO 223 II=1,NAZ
      JD(K)=ID(II)
      K=K+1
223  CONTINUE
      DO 224 JJ=1,JZ
      JD(K)=0
      K=K+1
224  CONTINUE
      N=NAZ+NZ
      CALL FILL(JD,ID,N,RATIO)
      CALL RGMGT (ID,IRG,N)
      WRITE TAPE ITB,(ID(K),K=1,N)
      N = MIN(130,N)
      PRINT 106, (ID(K),K=1,N)
201  CONTINUE
      END FILE ITB
      REWIND ITB
      PRINT 134
```

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```
GP TO 200
98 FORMAT (6X20A4,/)
99 FORMAT (20A4)
100 FORMAT (8F10.4)
101 FORMAT(6X14HPROGRAM. 9-75,20X30HG00DYEAR AEROSPACE CORPORATION,/)
102 FORMAT (6X33HSKEW CORRECTION AND SCALE PROGRAM,/)
103 FORMAT(16I5)
104 FORMAT(6X10HINPUT TAPE,15,/6X11HOUTPUT TAPE,14,/
1 6X28HNUMBER OF AZIMUTH SAMPLES 15,15,/6X27HNUMBER OF RANGE ELEMEN
2TS 15,16,/)
105 FORMAT(6X8HAZ SCALE,F12.1,5X8HRG SCALE F12.1,5X10HSKEW ANGLE F12.5
1,/)
106 FORMAT (1X,130I1)
134 FORMAT (1H1)
END
```

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```
      SUBROUTINE FILL (ID,JD,N,R)
C
C      ID IS THE INPUT ARRAY
C      JD IS THE OUTPUT ARRAY
C      N  IS THE NUMBER OF POINTS IN THE INPUT ARRAY
C      R  IS THE INCREMENT RATIO
C
C      N WILL BE RETURNED AS THE NUMBER OF OUTPUT POINTS
C
C      DIMENSION ID(2100)
C      DIMENSION JD(2100)
C
C      I = 1
C      X = 1.
C      XN = N
C      J = 2
200  CONTINUE
C      IF(X-XN) 201, 201, 202
201  CONTINUE
C      XJ = J
C      IF(Y-XJ) 203, 203, 204
204  CONTINUE
C      J = J+1
C      GO TO 201
203  CONTINUE
C      DY = ID(J)-ID(J-1)
C      Y = ID(J)
C      Y = Y-DY*(XJ-X)
C      IF(Y) 205, 205, 206
205  CONTINUE
C      JD(I) = Y-.5
C      GO TO 207
206  CONTINUE
C      JD(I) = Y+.5
207  CONTINUE
C      X = X+R
C      I = I+1
C      GO TO 200
202  CONTINUE
C      N = I-1
C      RETURN
C      END
```

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```

      SUBROUTINE INTDEN (ID,M)
      INTENSITY TO DENSITY
C
C
      DIMENSION ID(2100)
      DIMENSION JD(256)
C
C
      IF SCALE IS NOT KNOWN USE M=-N FOR FIRST CALL
      IF (M) 200, 210, 210
200 CONTINUE
      N = ABS(M)
      K = ID(1)
      DO 201 I = 2, N
      K = MAX(K, ID(I))
201 CONTINUE
C
C
      KIS = INTENSITY SCALOR          USE 0 IF THE SCALE IS NOT KNOWN
      KDS = DENSITY SCALOR          USE 128 FOR D=2
C
      READ 103, KIS, KDS
      IF (KIS) 202, 202, 203
202 CONTINUE
C
      KIS = K*64
203 CONTINUE
      PRINT 102, KIS, KDS
      ALGF = 1./ALOG(255.)
      XS = KDS
      DO 204 I = 1, 256
      X = I
      D = ALGF*ALOG(X)
      JD(I) = D*XS+.5
C
C
      JD(1) = 8
      204 CONTINUE
      RETURN
C
210 CONTINUE
      DO 211 I = 1, M
      K = ID(I)/KIS
      K = MIN(K, 256)
      K = MAX(1, K)
      ID(I) = JD(K)
211 CONTINUE
      RETURN
C
102 FORMAT (6X5HKIS =, I8, 10X5HKDS =, I10, /)
103 FORMAT (8I10)
      END

```

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```
      SUBROUTINE RGWGT (ID,M,N)
C
C      RANGE WEIGHTING FOR VERTICAL ANTENNA PATTERN CORRECTION
C      M = RANGE BIN
C      NEG M FOR INITIALIZATION IF REQUIRED
C
      DIMENSION ID(2100)
C
      IF (M) 200, 201, 201
200 CONTINUE
      RETURN
201 CONTINUE
      RETURN
      DO 202 I = 1, N
C
C      PUT WEIGHTING HERE
C
202 CONTINUE
      RETURN
      END
```

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